REDUCING OCCUPANT EXPOSURE TO VOLATILE ORGANIC COMPOUNDS (VOCs) FROM OFFICE BUILDING CONSTRUCTION MATERIALS: NON-BINDING GUIDELINES

DEPARTMENT OF HEALTH SERVICES

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Released: July 1996

PDF version created October 1999

Page numbers may not be correct

PREFACE

This document has been prepared by Leon Alevantis, M.S., P.E., Indoor Air Quality Section (formerly Indoor Air Quality Program), California Department of Health Services, in response to a California legislative mandate (Chapter 1229, Statutes of 1990, AB 3588, Speier). This mandate required the Indoor Air Quality Program to develop non-binding guidelines for the reduction of exposure to volatile organic compounds (VOCs) from building construction materials in newly constructed or remodeled office buildings. The guidelines presented here represent a simple technical approach for evaluating, selecting, and installing building construction materials in order to minimize occupant exposures to VOCs emitted from these materials. Some information on costs associated with this approach is discussed. However, a detailed economic analysis of the cost effectiveness of this approach is beyond the scope of the guidelines.

The guidelines are intended for use by building professionals such as architects, engineers, building contractors, product specifiers, interior designers, building owners, managers, and operators, and others interested in reducing VOC concentrations in new construction. The guidelines do not present any new methods or techniques; rather, the guidelines summarize the most significant information available on this subject. The guidelines are designed for application to building projects of any size that use mechanical ventilation, although elements of the guidelines can be applied to buildings that use natural ventilation.

Disclaimer

This document has been reviewed in accordance with the policies of the California Department of Health Services and the Health and Welfare Agency of the State of California. The contents are based on currently available scientific and technical information on the issues presented. Following the recommendations contained herein will reduce occupant exposure to VOCs emitted from office building construction materials but may **not** provide complete protection in all situations or against all health hazards related to such exposure. The guidelines presented in this document are **exempt** from the procedures for adoption of regulations, including review and approval by the Office of Administrative Law, pursuant to Chapter 3.5 (commencing with Section 11340) of Part 1 of Division 3 of the Government Code.

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EXECUTIVE SUMMARY

The guidelines presented in this document are the result of Chapter 1229 of the Statutes of 1990 (AB 3588, Speier - see Appendix A) that required the Indoor Air Quality Program (now Indoor Air Quality Section) of the California Department of Health Services (CDHS) to "develop nonbinding guidelines for the reduction of exposure to volatile organic compounds (VOCs) from construction materials in newly constructed or remodeled office buildings." The originating legislation was the result of concern about increasing complaints of sick building syndrome (SBS). This is a situation in which building occupants report symptoms, such as mucous membrane irritation, headaches, stuffiness, lethargy, and drowsiness, and which the occupants associate with a building. Researchers have reported that VOCs play a role in many SBS complaints, particularly in new or newly renovated office buildings, which often have substantial amounts of building and furnishing materials that emit VOCs.

The guidelines consider building **construction materials** to include not only <u>construction materials and products</u> but also <u>major furnishings</u>, such as office workstations, installed as part of a building's overall architectural and interior design. In addition, the guidelines address those <u>cleaning and maintenance materials and products</u>, the use of which are directly associated with the building construction materials and products selected.

The guidelines do <u>not</u> cover many other potential VOC sources such as: (a) occupant activities; (b) office equipment; (c) cleaning and maintenance products (other than the ones directly associated with the building construction materials selected); and (d) biological contaminants. These can be significant VOC sources in buildings. In addition, the guidelines do not provide special design considerations for accommodating those building occupants who are especially sensitive to VOCs.

The guidelines provide the best currently available information on minimizing occupant exposures to VOCs from office building construction materials. It should be noted that information in this field is evolving rapidly. For example, a number of testing methods for various building materials (e.g., carpet and paints) are being developed and will become available in the next few years. Also many product manufacturers continue to reduce emissions from their products. While specific information may change, the general guidance presented here is based on general methods and procedures for evaluating, selecting, and installing new building materials and therefore will still be applicable as information evolves. The guidelines have been written primarily for application to office buildings of any size that use mechanical heating, ventilating, and air-conditioning (HVAC) systems. However, the guidelines can be applied to most building types such as mixed-use buildings (e.g. libraries and courthouses). In addition, elements of the guidelines can be applied to naturally ventilated buildings.

The guidelines are intended for use by building professionals such as architects, engineers, building contractors, product specifiers, interior designers, building owners and operators, and others interested in reducing VOC concentrations in new construction. The guidelines do not present any new methods or techniques; rather, they summarize the most significant information currently available on this subject. Finally, the guidelines are <u>**non-binding**</u> and have <u>**no**</u> regulatory authority

The guidelines recommend a five-step approach to reducing exposure to VOCs from building materials and products. These five steps are listed below.

Step 1. <u>Evaluate and select low-VOC-impact building materials and products</u>: This is the most critical step in minimizing human exposure to VOCs emitted from building materials and products. In order to assess the impact of emissions from building materials, the guidelines define a **low-**

VOC-impact building material or product as one that when installed in a building results in minimal or reduced exposure of occupants to VOCs that are emitted from the material or product. Note that this definition does not necessarily imply that a low-VOC-impact material is also low-VOC emitting. The evaluation and selection of these materials and products is a four-step process as indicated in Figure 1 and discussed next.

Task 1: identification of target materials and products based on estimated installed quantities, proximity of installed materials and products to occupied zones, adsorption characteristics of some materials, and identification of materials and products with known high VOC emission rates;

Task 2: collection of more detailed VOC-related product information on candidate materials and products using manufacturers' lists of Material Safety Data Sheets (MSDSs) (MSDSs typically contain information about a material's chemical contents as well as information on the potential adverse health and safety effects resulting from exposure to these contents), product specifications listing chemical contents, results of emissions testing data, and other sources such as lists of carcinogenic contents;

Task 3: evaluation of building products and materials based on MSDSs, reactive VOC contents, calculated chemical emissions using vapor pressures and mass transfer coefficients, results of emissions testing, and estimated indoor concentrations; and

Task 4: selection of building products based on MSDSs and/or emissions testing results as shown on Figure 2. Selection of products based on MSDSs alone is complicated by the lack of industry standardization of the reported information, and the fact that MSDSs are sometimes incomplete or inaccurate failing to list all potentially hazardous substances. Furthermore, selection of products based on comparison of emissions testing data of functionally equivalent building products requires consideration of the following issues:

a) there is lack of standard emissions testing and reporting methods for VOCs (a summary of existing testing methods is presented);

b) total volatile organic compound (TVOC) results for the same mixture of components analyzed by different methods can vary by a factor of two or more due to differences in sample collection methods, TVOC calibration methods, and data reduction and analysis;

c) accuracy of TVOC results depends on the mixture of compounds being analyzed;

d) variation in history, age, condition of the tested material, and in environmental factors (i.e., ventilation, air velocities, temperature, and humidity of tested material samples) can affect reported emission factors by several orders of magnitude; and

e) delivered materials may have emissions different from tested samples (an issue that is difficult to address unless random testing of delivered materials is performed after delivery).

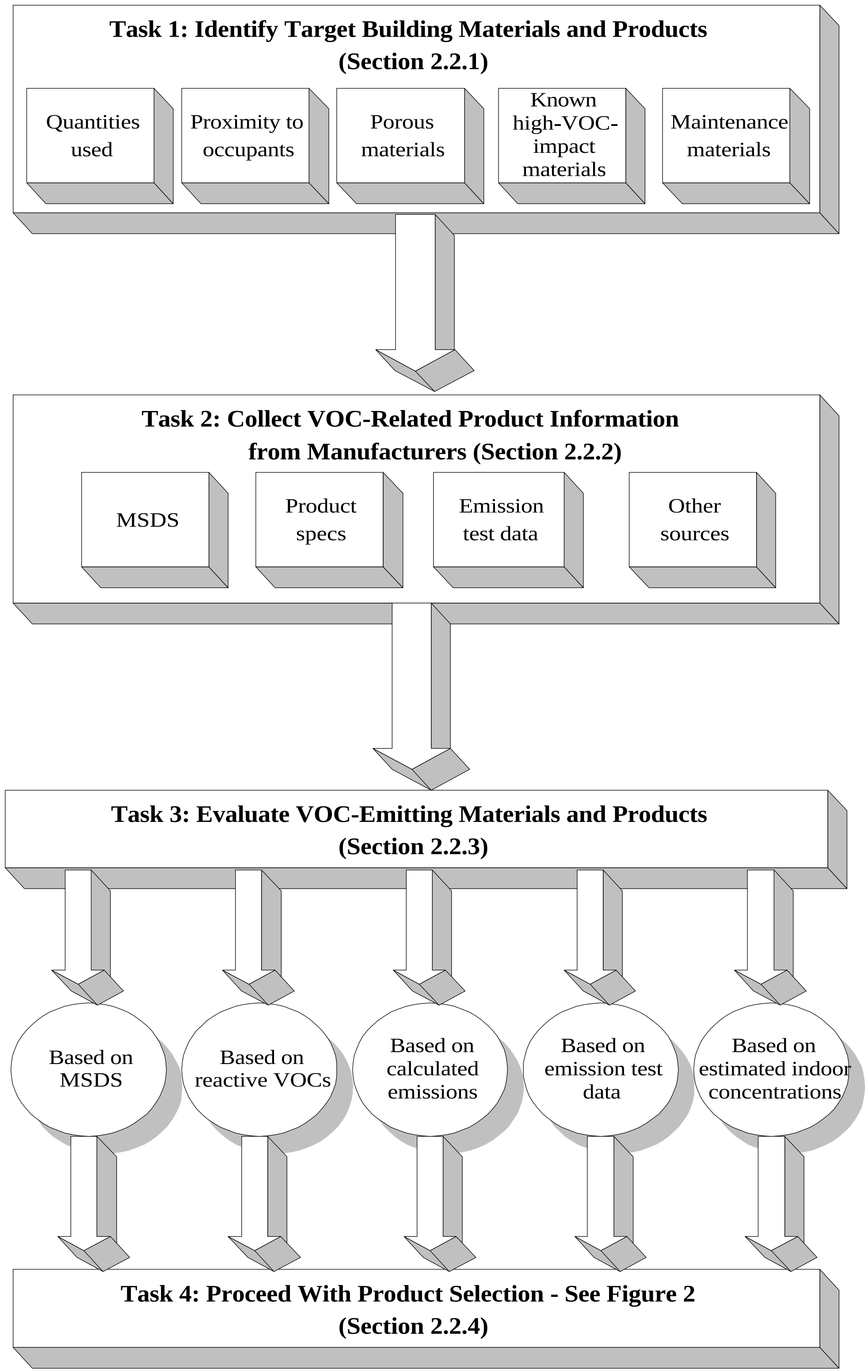

Figure 1. Four-Step Strategy for Evaluating and Selecting Building Materials and Products

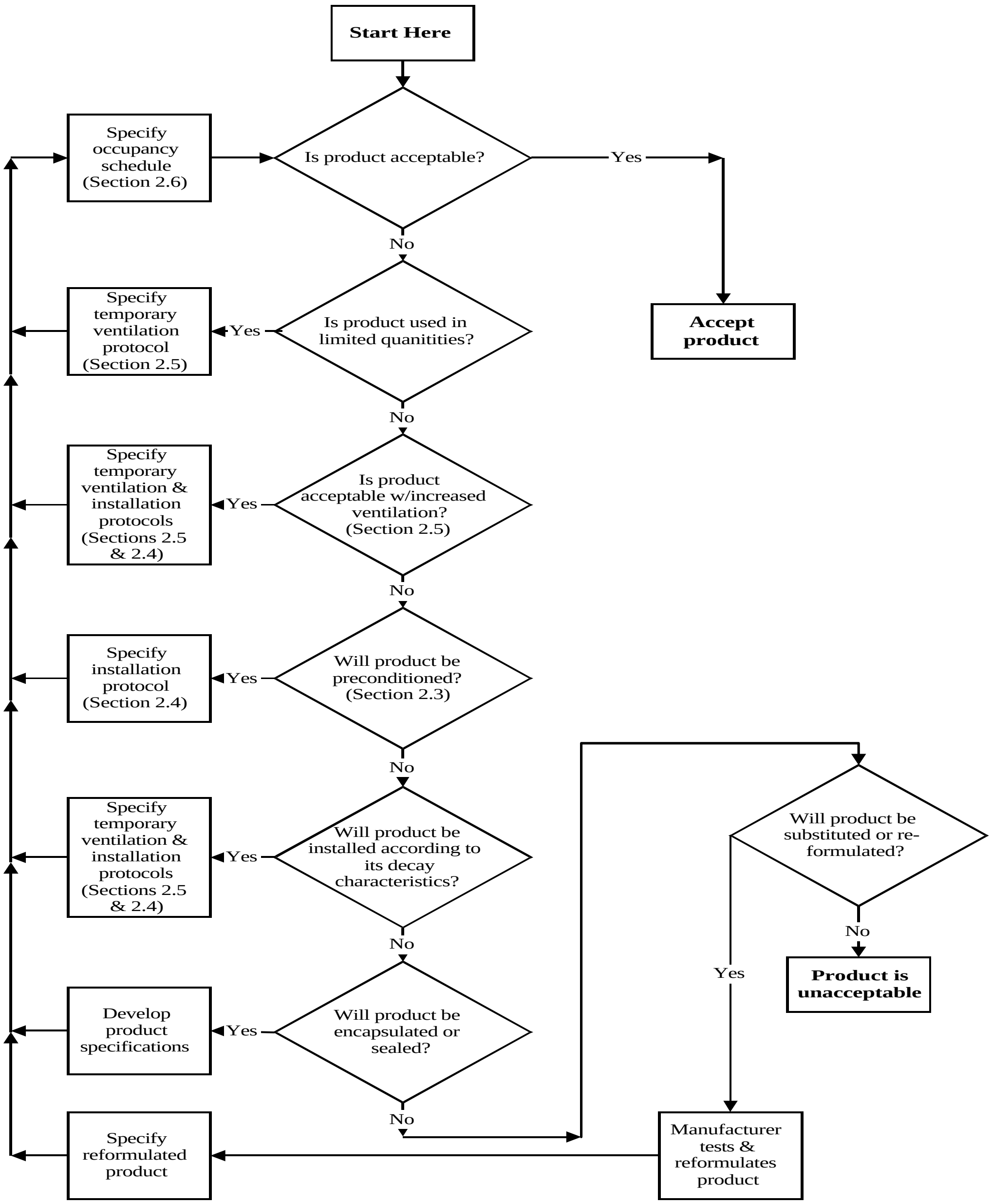

Figure 2. Flow Chart for Selecting Building Materials and Products

The above issues can be addressed before seeking bids from contractors and then should be verified in the submitted stage so that comparison of emission factors of functionally equivalent products can be made. Sample language for contract documents addressing the above issues is included in the present document. (Documents drawn in the pre-bid phase are referred to as **construction documents**.) Note that TVOC emission rates must be used to compare similar products with similar chemical compositions that have been tested using the same analytical methods.

Emissions testing data can assist a designer in comparing functionally equivalent products and making selections based on this comparison. However, it is difficult to select materials and products based on predictions of indoor VOC concentrations derived from emissions testing data because of the following uncertainties:

a) indoor VOC concentrations cannot be predicted accurately based on emissions testing data because of the time, space, and building dependency of such predictions (however, a simplified equation for estimating indoor concentrations from emission factors is presented); and

b) even if VOC concentrations could be predicted accurately based on emissions testing data, interpretation of indoor VOC concentrations would be difficult due to lack of health-based guidelines for most indoor pollutants found in non-industrial indoor environments. (A summary of existing guidelines for selected VOCs is presented as well as a survey of existing product labeling programs in the United States and Europe.)

Because of these complex issues, the guidelines focus on selecting building construction materials with low emission rates rather than on attempting to meet specific concentrations. It is important to note that considerations other than VOC emission rates may need to be made as part of the selection process of building materials. These considerations may include: acoustical properties, comfort properties, local building codes, architectural qualities, durability, warranty, and maintainability. (Note that the remaining four steps also have been incorporated in Figure 2.)

Step 2. Pre-condition certain materials to minimize VOC emissions after installation: This step includes conditioning of materials at the manufacturing or assembly facility, at a "bonded" warehouse with appropriate ventilation, or in a dry, well-ventilated area other than the one where the materials will be installed, until emissions have been reduced. Examples of these materials include office furniture and carpeting. Note that storage of certain materials after manufacturing is unavoidable especially in cases of special production orders or large quantities. For example, in the case of carpeting for a large-size building, there may be a time lag of several months between production and delivery of the product. In such cases storage is unavoidable and specifying a dry, well-ventilated space may not add a considerable cost to a project. There are no field data demonstrating the minimum length of time needed to effectively pre-condition various building products.

Step 3. Install building materials and products based on their VOC emission decay rates: This step involves the phased installation of building materials and products based on their emission and adsorption characteristics. Typically **wet** products such as paints, adhesives, and taping and deck leveling compounds should be installed first. Wet products are typically characterized by very high initial emissions followed by much lower emissions. This is because most solvents and other chemicals in wet products are emitted for a few hours or days after installation. Porous materials, such as carpets and fabric-covered office dividers, should be installed last. This technique minimizes adsorption by porous materials of the VOCs initially emitted by wet products and subsequent re-emission at a later time (a process known as the **sink effect**).

Step 4. <u>Ventilate a building during and after installation of new materials and products</u>: The maximum amount of outside air should be provided during and after installation of VOC-emitting materials for the maximum amount of time feasible (this process is known as a building **flush-out**). There are no data on the recommended duration for building flush-outs, but a conservative approach is to flush-out as long as economically feasible, but not less than continuously (i.e., 24 hr) for seven days. It should be noted that the maximum amount of ventilation provided by an HVAC system may be limited not only by the system's capacity but also by the temperature and humidity of the outdoor air. Special procedures during partial building renovation/remodeling (i.e., completely isolating the air between occupied areas and areas under construction) should be followed and are discussed. The guidelines summarize and encourage compliance with ASHRAE's recommendation on **HVAC commissioning** (i.e., a process that ensures that the performance of an HVAC system meets design parameters) in order not only to minimize exposure to VOCs but also to improve indoor air quality during the life of a building.

Step 5. <u>Delay occupancy until VOC concentrations have been reduced adequately</u>: Because VOC concentrations are highest during and immediately after construction, it is important to allow sufficient "flush-out" time before occupants move in. Air samples can be taken to verify that indoor VOC concentrations have been reduced sufficiently prior to occupancy. It should be noted that: (a) guidelines exist for only a few VOCs; (b) there are no standard testing methods for TVOCs; and (c) existing guidelines for TVOCs are not widely accepted. However, TVOC concentrations can be used to compare a building's indoor air with measurements taken in other non-problem buildings.

A detailed economic analysis of all the costs associated with the above five steps is beyond the scope of the guidelines. However, some of these costs are discussed. Unfortunately there is very limited published information on this subject. Based on this limited information, it appears that the highest cost of reducing occupant exposure to VOCs is associated with emissions testing of building materials, especially when many products must be tested. The cost of testing individual products based on the **headspace** sampling technique ranges between $1,000 and $2,000, whereas the cost of testing large-size products, such as complete office workstations, in **environmental chambers** exceeds $5,000 depending on many factors such as test duration, number of test air change rates, number of samples tested, etc. Other costs, such as design fees, cost of building materials, cost of increased ventilation, and cost of delayed occupancy, also need to be considered. Limited data indicate that design fees are low, accounting for less than 1 percent of the Architectural/Engineering (A/E) fees of a project (A/E fees for high-rise office buildings typically account for between 4 and 6 percent of the construction cost). Although the cost of building materials account for a major portion of the construction cost (typically between 30 and 60 percent), their cost is usually independent of their emission characteristics (i.e., lower VOC emissions do not necessarily imply higher cost). Small premiums charged for some low-VOC-emitting materials are likely to be reduced or eliminated as demand for these products increases. Finally, other costs such those resulting from increased ventilation and delayed occupancy are project-specific. It is important for building owners and employers to realize that if poor indoor quality increases the absenteeism rate by only 2.5 percent (OSHA estimated this rate to be 3 percent) then the increased annual costs associated with this increased absenteeism rate is comparable to the cost of utilities or maintenance and operation of a building. Other economic impacts of improved indoor air quality also must be considered. These include reduced liability exposure, improved building marketability, reduced health care costs, lower operating costs, and increased occupant comfort and productivity.

Other topics mandated by AB 3588 and discussed in the guidelines include the following:

1. Discussion of the appropriateness of mandatory regulations: Due to the limited information available for selecting low-VOC-impact materials and the lack of standard testing methods for building materials, consideration or development of mandatory regulations is inappropriate at this time. Compliance with the guidelines is encouraged on a non-binding, voluntary basis. Product manufacturers are encouraged to develop voluntary labeling programs as more standard testing methods for various building materials become available.

2. Discussion of the usefulness of formation of an ad hoc committee of professionals and other interested parties: The guidelines encourage the formation of a multi-disciplinary committee of professionals to further review the guidelines, to make recommendations for modifications, and to advise the CDHS on the practicality of the guidelines based on the field experience of the committee's members. In addition, the guidelines recommend the formation of a central repository for product emission information and current product regulations.

3. Discussion of a process known as building **bake-out**: This is a process designed to "artificially age" building materials and products by elevating the temperature of an unoccupied, newly constructed or remodeled building while supplying a fixed amount of ventilation, and flushing the building with the maximum possible ventilation after completion of the bake-out. Due to problems associated with this process and its questionable effectiveness, the guidelines do not recommend building bake-outs. Instead, the guidelines recommend selection and installation of low-VOC-impact materials and products followed by a building flush-out. However, some technical aspects of building bake-outs are discussed.

ACKNOWLEDGMENTS

Leon Alevantis, M.S., P.E., Indoor Air Quality Section, California Department of Health Services (CDHS), gratefully acknowledges the generous contribution of time and effort on the part of the many people who contributed to the development and review of the guidelines. **Peter Flessel**, Ph.D., Chief, Environmental Health Laboratory Branch (EHLB), CDHS, provided guidance and critical editorial comments during the development of this document. **Jed Waldman**, Ph.D., Chief, Indoor Air Quality Section, EHLB, CDHS, provided advice and support during the latter development stages of this document. A steering committee, formed during the initial stages of the development of the guidelines, provided general guidance on the scope of the guidelines (see page xviii for a list of steering committee members). Numerous individuals reviewed the guidelines, either in part or in their entirety, and helped shape its final form (see pages xix - xxii for a list of reviewers). (Note: Review of the Guidelines by an individual or organization does **not** imply their endorsement of the final version of the guidelines.) Portions of selected sections presented in this document were based on material originally written by: (a) the late **Steven Hayward**, Ph.D., Chief, Indoor Air Quality Section, EHLB, CDHS; and (b) **Hal Levin**, B.S., as published by him in *The Indoor Air Bulletin*. **Sharon Seidel**, Ph.D., Environmental Health Investigations Branch, CDHS, provided input on the health effects of VOCs (Sections E2 and E4 of Appendix E). **Jim Cone**, M.D., M.P.H., Hazardous Evaluation System and Information Services Section, Occupational Health Branch, CDHS, also provided input on the health effects of VOCs (Section E2 of Appendix E). **Peggy Jenkins**, Indoor Air Quality Program, California Air Resources Board, provided the text on the California regulations for architectural coatings and consumer products of Appendix H. **Richard Lam**, Ph.D., Indoor Air Risk Assessment Group, Air Toxicology and Epidemiology Section, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, provided input on the sensory effects of VOCs (Section E4 of Appendix E). **Janet M. Macher**, Sc.D., M.P.H., Indoor Air Quality Section, EHLB, CDHS provided critical editorial review.

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SECTION 1. INTRODUCTION

1.1 Statutory Mandate

Chapter 1229 of the Statutes of 1990 (AB 3588, Speier - see Appendix A) mandated the addition of Section 426.10 to the California Health and Safety Code (Appendix A). This legislation requires the Indoor Air Quality (IAQ) Program (now IAQ Section) of the California Department of Health Services (CDHS) to develop non-binding guidelines for reducing occupant exposure to volatile organic compounds (VOCs) from office building construction materials. The guidelines address the various mandated topics of this legislation in the following sections.

1. Mandated topic: "The type of building to which the guidelines shall apply."
   Addressed in: Section 1.1.

2. Mandated topic: "The methodology for identifying indoor sources of VOCs."
   Addressed in: Sections 1.5.2, 2.2, 2.3, 2.4, 2.5, and 2.6.

3. Mandated topic: "The bake-out procedures prior to occupancy for newly constructed buildings."
   Addressed in: Section 3.3 and Appendix D.

4. Mandated topic: "The procedures for VOC reduction during and after major remodeling of occupied buildings."
   Addressed in: Sections 1.5.2, 2.2, 2.3, 2.4, 2.5, and 2.6.

5. Mandated topic: "The need to establish mandatory regulations rather than nonbinding guidelines for the procedures to reduce VOC exposure in newly constructed buildings and during the remodeling of buildings and, in addition, the need for regulation regarding the occupancy of a newly constructed building or a building undergoing remodeling where VOC reduction is to be considered."
   Addressed in: Section 3.1.

6. Mandated topic: "The need to establish an ad hoc group of building construction material manufacturers, builders, building owners and managers, organized labor, sheetmetal contractors, plumbing contractors, mechanical engineers, architects, and building inspectors to advise the state department on procedures and costs related to implementing the proposed guidelines."
   Addressed in: Section 3.2.

The guidelines presented in this document are based on the best currently available knowledge in this field. Their application is likely to result in reduction of occupant exposures to VOCs from office building construction materials. The information presented covers a comprehensive technical approach for evaluating, selecting, and installing building construction materials. The guidelines have been written primarily for application to buildings that use mechanical heating, ventilating, and air-conditioning (HVAC) systems, although elements of the guidelines can be applied to buildings that use natural ventilation. The guidelines are non-binding and have no regulatory authority. They are intended for use with any size office building However, the guidelines are applicable to most building types such as mixed-use buildings (e.g., libraries and courthouses).

1.2 Purpose of the VOC Guidelines

The guidelines are intended for use by building professionals, such as architects, engineers, building contractors, product specifiers, interior designers, building owners and operators, and others interested in reducing VOC concentrations in new construction. The guidelines do not present any new methods or techniques; rather, they summarize the most significant information currently available on this subject.

It is not the purpose of the guidelines to teach building designers, owners, or other building professionals the basic principles of achieving or maintaining good indoor air quality. The reader is referred to *Building Air Quality: A Guide for Building Owners and Facility Managers* (USEPA, 1991) for such information. (See also Section K8 of Appendix K for other publications on indoor air quality.) It is also not the purpose of the guidelines to provide instruction on how to investigate or mitigate existing indoor air quality problems. Protocols for such activities have been published elsewhere [see, e.g., USEPA (1991)]. However, the guidelines provide a listing of other information resources, such as professional building-related organizations (see Appendix K: Information Resources).

1.3 The Need for Guidelines

Chapter 1229 of the Statutes of 1990 (AB 3588, Speier - see Appendix A) was the result of concern about increasing complaints of sick building syndrome (SBS). This is a situation in which building occupants experience symptoms, such as nose, eye, and throat irritation, sneezing, stuffy or running nose, fatigue or lethargy, headache, dizziness, nausea, irritability, and forgetfulness, and which the occupants associate with the building (USEPA, 1993b).

There have been various estimates on the number of buildings experiencing SBS symptoms. A committee of the World Health Organization (WHO) estimated that up to 30 percent of new and remodeled buildings worldwide may experience SBS (WHO, 1986; USEPA, 1993b). Based on a stratified random telephone survey of 600 U.S. office workers, Woods et al. (1987) concluded that 20 percent of office workers in the U.S. are exposed to SBS (OSHA, 1994a). In California, the Occupational Safety and Health Administration (Cal-OSHA) estimated that occupants in approximately 1,000 California buildings experience SBS each year (Cal-OSHA, 1985). Since most of these buildings have many occupants, SBS is a problem that can affect the health and productivity of many workers.

Researchers have reported that increased concentrations of indoor VOCs are often associated with increased occupant health complaints (Mølhave, 1990; Fisk et al., 1993; Mendell, 1993; Ten Brinke, 1995). It is well known that new building materials and products emit VOCs and that their emissions decrease with time at rates characteristic of each product or material. It is therefore not unusual for occupants of new and newly renovated office buildings with non-operable windows and substantial amounts of new building and furnishing materials to report a number of health complaints.

Mølhave (1990) estimated that 50 to 300 different VOCs are typically detected in the indoor air of non-industrial buildings. VOCs typically represent a broad range of chemical compounds sampled by absorption on a solid sorbent with boiling points between 50 and 260°C (WHO, 1987a). However, some other compounds are included for convenience although they do not have boiling points within 50 and 260°C [e.g., methylene chloride (boiling point: 40.1°C) and formaldehyde (boiling point: -19.5°C)].

VOCs are just one part of indoor air pollution that occupants of office buildings are exposed to. Other environmental factors, often beyond the control of most occupants in modern buildings, include amount of ventilation, temperature, humidity, dust, bioaerosols, air velocity, "radiant" temperature of surrounding surfaces, noise, and lighting.

1.3.1 Health Effects of VOCs

Indoor air pollution including exposure to VOCs may result in short- and long-term health effects at concentrations typically measured in non-industrial environments. The United States Environmental Protection Agency (USEPA) reported that long-term health effects "...can be severely debilitating or fatal" and "...may show up years after exposure has occurred or only after long or repeated periods of exposure" (USEPA, 1993a). According to the USEPA, long-term health effects include respiratory diseases and cancer. Short-term health effects are usually treatable and "...may appear after a single, high-dose exposure or repeated exposures" (USEPA, 1993a). Short-term health effects include "...irritation of eyes, nose, and throat, headaches, dizziness, and fatigue" (USEPA, 1993a).

Additional available information suggests that VOC exposures can result in adverse health effects at concentrations typically measured in non-industrial environments (Franck, 1986; Kjærgaard et al., 1990; Mølhave, 1990). These effects are typically concurrent with the exposure and may include: (a) sensory detection, often by odor, of the air contaminants; (b) physiological irritation or inflammation of exposed skin, eyes, and mucous membranes; and (c) stress reactions to the perceived chemical (Mølhave, 1990). Tearing of the eyes; runny nose; stinging, itching, or tingling feelings in exposed tissues; changes in skin temperature; headache; and drowsiness are some common symptoms seen with exposure to VOCs in non-industrial environments. Some health effects, such as nose and throat irritation, may occur with the first exposure to indoor VOCs, whereas other health effects, such as systemic and carcinogenic effects, may be delayed for years.

Health effects more serious and long-term than immediate irritation have been suggested to occur with repeated exposure to indoor VOCs. These include a wide range of systemic effects such as asthma and other chronic respiratory illnesses, reproductive effects, and cancer. There is very little direct evidence for the occurrence of these more serious effects in non-occupationally exposed humans, either in the general population or in sensitive sub-populations such as children, the elderly, and people with pre-existing respiratory conditions. However, studies of individual VOCs in animals, and in some cases occupational exposures in humans, have shown the potential for long-term effects at elevated levels of exposure.

Most information on the health effects of VOCs is related to exposures to individual compounds rather than to mixtures that could be combinations of tens to hundreds of such compounds. In addition, very little is known about some of the potentially irritating chemicals emitted by new materials, especially when people are exposed to combinations of such chemicals in non-industrial settings (e.g., offices). Furthermore, adequate information on the health effects of a large number of VOCs found in indoor air is not available and many chemicals present indoors are not reported due to analytical methods used or cost.

It should be noted that for a non-cancer-causing chemical, there is usually some level of exposure, or threshold, that is necessary before an adverse health effect occurs. Carcinogens, on the other hand, are believed to have no threshold of exposure, that is to say, even very low levels of exposure may carry some risk for developing cancer. Animal studies have suggested that a combined exposure to several common indoor VOCs over a lifetime may result in an excess cancer risk (McCann et al., 1988). It is noted that most of the available information on the carcinogenic effects of VOCs are based on individual VOCs tested on animals. However, a limited number of individual VOCs have human carcinogenic data (e,g., benzene).

1.3.2 Economic Impacts of Poor Indoor Air Quality

One of the major economic impacts of poor indoor air quality is reduced employee productivity. It is important for building owners and employers to realize that the employee costs (i.e., salaries and wages) far exceed building construction or leasing costs. Table 1 demonstrates this point by presenting typical annual costs associated with owning and operating buildings in the United States as reported by Woods (1989). Although actual costs may differ today, Table 1 clearly shows the relative differences among the various annual costs. The single most expensive item is salaries and wages. It is important to note that if poor indoor quality increases the absenteeism rate by only 2.5 percent (i.e., from a typical 5 to 7.5 percent) then the increased annual costs associated with this rate (i.e., 3 to 5 $\$/ft^2$; 28 to 55 $\$/m^2$) can be comparable to the cost of utilities or maintenance and operation of a building. The United States Occupational Safety and Health Administration (OSHA) estimated that employee productivity loss due to poor indoor air quality to be 3% (OSHA, 1994a). Thus poor indoor air quality could produce changes in productivity resulting in significant economic impacts especially if the situation persists for years. In extreme cases, a major SBS episode can disrupt drastically the productivity of a business for a long time.

However other economic impacts of improved indoor air quality must be considered. These include reduced liability exposure, improved building marketability, reduced health care costs, lower operating costs, and increased occupant comfort and productivity.

Table 1. Building- and Employee-Associated Costs Per Floor Area (Woods, 1989)

Item	Annual Cost, $\$/ft^2$ ($\$/m^2$)
Construction (net floor area)	8 to 40 (86 to 430)
Capital assets (furniture and equipment)	2 to 35 (22 to 380)
Maintenance and operation	2 to 4 (22 to 43)
Utilities	2 to 4 (22 to 43)
Rented or leased space	15 to 50 (160 to 540)
Salaries and wages	**100 to 200 (1100 to 2200)**
Typical absenteeism @ 5%	5 to 10 (55 to 110)
Increased absenteeism @ 7.5%	8 to 15 (83 to 165)

1.4 VOC Sources Addressed in the Guidelines

VOCs are organic compounds that have sufficiently high vapor pressures to exist as gases or vapors at ambient temperatures. Most materials and products used in the construction and finishing of interior office spaces are potential sources of VOCs. These include paints, adhesives, sealants, caulks, carpets, vinyl floor and wall coverings, composite wood products, drywall products such as taping compounds, concrete deck leveling compounds, furniture finishing products, and insulation materials. Furnishing materials, such as furniture and interior panels, are also likely VOC sources. Researchers have estimated that up to 300 different VOCs are typically detected in the indoor air of non-residential buildings. A selected number of

VOCs that may be emitted from building materials and cleaning products and their potential indoor sources are listed in Appendix B.

However, building construction materials and furnishings are not the only sources of indoor VOCs. Heating, ventilating, and air conditioning (HVAC) systems, building maintenance and cleaning products, consumer products, combustion processes such as combustion appliances and tobacco smoking, and occupants themselves also are potential sources of indoor VOCs.

Section 426.10 of the California Health and Safety Code specifically requires that the CDHS "shall develop nonbinding guidelines for the reduction of exposure to VOCs from construction materials in newly constructed or remodeled office buildings." The guidelines presented in this document consider building **construction materials** to include not only construction materials and products but also major furnishings that are part of a building's overall architectural design. In addition, the guidelines address those cleaning and maintenance materials and products the use of which is directly associated with the selected building materials (as discussed in Section 2.2).

The guidelines do not cover other potentially significant sources of indoor VOCs such as: (a) occupant activities; (b) office equipment; (c) cleaning and maintenance products (other than those directly associated with the building materials selected); and (d) biological contaminants. In addition, the guidelines do not address any special design considerations or other issues related to occupants who are especially sensitive to VOCs.

1.5 Dynamics of VOC-Emitting Building Materials and Products and of VOC Sinks

As note above, most building materials and products emit various amounts of VOCS. Unfortunately, very little information exists in the literature on emission rates from specific products and materials. Researchers in the United States and Europe have reported limited amounts of information. Levin (1991) compiled information from nine of these studies and listed VOC emission data for various building materials and furnishings. According to Levin's list: (a) some of the higher-emitting materials include adhesives, vinyl floor coverings, and particleboard; and (b) reported emission factors for similar products and materials may vary by one or more orders of magnitude. For example, emission factor (i.e., mass of an individual volatile organic compound or mass of total measured volatile organic compounds emitted from a material per unit of material or product area per unit of time; emission factor unit is $\mu g/m^2{\cdot}hr$) of adhesives used to glue down carpeting has been reported to be as low as 783 $\mu g/m^2{\cdot}hr$ and as high as 153,000 $\mu g/m^2{\cdot}hr$ (Levin, 1991). Although some of the reported differences may be due to the age of analyzed samples, the data indicate that large differences do exist for functionally equivalent products.

Manufacturers are increasingly likely to have their products tested and to make emission data available to the public because architects and other building professionals are requesting such information. For example, the Carpet and Rug Institute (CRI) has initiated a voluntary testing program and has established maximum emission factors for new styrene butadiene rubber (SBR) latex-backed carpets for four parameters: TVOCs, styrene, 4-PC (4-phenylcyclohexene), and formaldehyde (CRI, 1994a). (See Appendix C for a discussion of this and other product labeling programs.)

1.5.1 VOC Sinks

VOCs and other chemicals present in the indoor air may adsorb onto surfaces of many materials. Porous materials, often termed "fleecy," are of special concern. Such materials can be "VOC sinks" and include fabric upholstery, carpets, insulation, wallboard, and other porous indoor materials. The amount of VOCs adsorbed depends on their volatility, polarity, temperature and concentration as well as their affinity for the surface of a particular material. In general, the higher the surface area of a material the greater the sink potential. Glass and metal surfaces have the lowest adsorption characteristics, textiles have the highest, and wood and plastics have intermediate adsorption characteristics. Adsorption usually occurs in indoor environments with high VOC concentrations. When the concentration of VOCs in the air drops, the equilibrium between gas-phase VOCs and surface VOCs results in higher air concentrations for longer times than would result from the original source in absence of sinks. Thus the sink effect of VOCs can increase significantly the time required to reduce indoor VOC concentrations.

The following two examples show the importance of VOC sinks.

1. Tichenor et al. (1988, 1991) reported that para-dichlorobenzene, a constituent of moth repellants, was measured in significant concentrations in a house several days after the source was removed. Measurements in the same house a year after the source was removed showed higher indoor than outdoor concentrations of para-dichlorobenzene, thus indicating re-emission of this compound previously adsorbed on interior surfaces.

2. Seifert and Schmahl (1987) reported that the formaldehyde content of a 2-m^2 curtain was increased from 140 to 400 ng/cm^2 after storage for several days in a 12-m^3 aluminum test chamber containing urea formaldehyde foam (the resulting formaldehyde concentration within the chamber was 370 $\mu g/m^3$). The curtain subsequently was wrapped in aluminum foil and stored outside the test chamber while the chamber was ventilated to remove all remaining formaldehyde. When the curtain was returned to the chamber, the formaldehyde concentration increased to 170 $\mu g/m^3$.

1.5.2 Characterization of VOC Sources

VOC sources can be characterized according to the duration of their emissions, the type of application, or sink characteristics and are discussed next.

1.5.2.1 Characterization According to VOC Emissions.

Building materials can be characterized by the duration of their VOC emissions. Duration and amount of VOC emissions determine the level of occupant exposure. Materials may be classified in one of the following three categories based on whether VOC emissions decay slowly, intermediately, or rapidly (Tucker, 1991).

1. <u>Materials with slowly decaying VOC emissions</u>: These materials are characterized generally by low initial VOC emissions and **half-life** emission rates (i.e., time it takes for the initial emission rate to be reduced by one-half) of a year or more. As a result, these materials emit VOCs at fairly constant rates over long time periods. Examples of such materials include pressed wood products such as plywood and particleboard containing formaldehyde-based resins.

2. <u>Materials with intermediately decaying VOC emissions</u>: These materials are characterized by either high or low initial VOC emission rates and "half-life" emission rates ranging from a few weeks to several months. As a result, VOCs from these materials can be detected for several weeks or months after installation. Examples of such materials include certain types of floor and wall coverings, and caulks and fillers applied in continuous beads.

3. <u>Materials with rapidly decaying VOC emissions</u>: These materials are characterized by high VOC emissions during and immediately after installation and by half lives ranging from a few minutes to a few days. As a result, most (i.e., 95 percent or more) of their lifetime emissions occur within hours or

days after installation. Examples of such materials include thin-film, wet-applied products that dry very quickly, such as paints, sealants, and adhesives.

1.5.2.2 Characterization According to Application or Sink Characteristics.

VOC-emitting building materials can be categorized according to their application or sink characteristics (Levin, 1992a) as listed below.

1. "Wet" Products: These products include paints, wood stains, sealants, adhesives, caulks, and sealers. Most solvents and other chemicals in such products are emitted for a few hours or days after installation. However, some of these products, such as caulks and fillers applied in continuous beads, and latex paints applied to gypsum wallboards may have high initial emission rates, as do other wet products, but also may continue to emit VOCs at much lower rates (e.g., 1,000 to 10,000 times lower) for weeks, or even months, after installation.

2. "Dry" Products: These products include floor and ceiling products and solid and composite wood products. VOC emissions are usually due to solvents used in the manufacturing process of the product or its constituents. Dry products, unlike wet ones, initially emit low amounts of VOCs and may continue to emit for weeks, months [e.g., styrene butadiene rubber (SBR) latex-backed carpet], or even years (e.g., composite wood products made with formaldehyde-based resins). Typically, emission rates decrease with time by as much as 100 fold in a few weeks.

3. "Porous" Products: These products include textiles such as fabric upholstery, carpets, wood products, insulation, paper, gypsum wallboard, and other porous indoor materials. Porous products may act as secondary sources (i.e., sinks as discussed in Section 1.5.1) of the chemical compounds to which they were exposed and which they trapped. This process depends on the volatility, polarity, and concentration of the chemical compounds as well as their affinity for the surface of the porous product. Porous materials acting as secondary sources can affect considerably the decay rate of indoor VOC concentrations, thus prolonging the duration of exposure.

1.5.3 Factors Affecting VOC Emissions from Building Materials

At least six major factors influence the emissions rates and resulting indoor concentrations of VOCs from building materials (ASTM, 1990a; Tucker, 1991; Tichenor and Guo, 1991).

1. Total content of vaporizable constituents in the material. Listed constituents may not include impurities or other contaminants. For example, the manufacturer of a spray adhesive lists the following information (note that the **VOC content** refers to **reactive VOCs** as discussed in Appendix H):

   a) VOC content: 682 g/L (5.69 lbs/gal); and

   b) Contains: Dimethyl ether (CAS # 115-10-6), Pentane (CAS # 109-66-0), Cyclohexane (CAS # 110-82-7), Non-volatile components (N.J. Trade Secret Registry No. 04499600-5468P), and Naphthol spirits (CAS # 64742-48-9).

   Similarly, the manufacturer of a spray adhesive remover lists the following information:

   a) VOC content: 699 g/L (5.83 lbs/gal) or 92 percent; and

   b) Contains: Isopropyl alcohol (CAS # 67-63-0), Naphthol spirits (CAS # 64742-48-9), Propane (CAS # 74-98-6), Amorphous silica (CAS # 7631-86-9), Ethylene glycol (CAS # 107-21-1), Isobutane (CAS # 75-28-5), Butane (CAS # 106-97-8), and Ethane (CAS # 74-84-0).

2. Distribution of VOCs within the mass of a material resulting in diffusion-dominated or surface-dominated processes. Thick solid materials, such as composite wood products, have slow emission rates because chemicals, such as formaldehyde, must migrate by diffusion from deep within the material to the surface before they evaporate into the air. Wet processes, such as paints and adhesives, have emission bursts during and after application, because most chemicals are at or near the surface of the material.

3. Age and history of material since manufacturing, assembly, or installation. This is a very important factor because most building materials have emission rates that decrease with time. Typically, emission rates of wet products decrease by several orders of magnitude within a few hours after installation, whereas, emission rates of other materials, such as pressed wood products, may take several years to decrease. For example, Tucker (1991) reported that the emission factor of a new particleboard was 2,000 $\mu g/m^2 \cdot hr$, whereas the emission factor of a two-year old particleboard was 200 $\mu g/m^2 \cdot hr$. Tucker also reported that the emission factor of a 0.2-m^2 strip of silicon caulk less than 10 hr after application was 13,000 $\mu g/m^2 \cdot hr$, and that the emission factor decreased to less than 2,000 $\mu g/m^2 \cdot hr$ after between 10 and 100 hr following application. The age of a material must be taken into consideration when comparing emission factors of functionally equivalent materials as discussed in Section 2.2.3.4.

   The history of a material (i.e., the conditions the material was exposed to during aging time) also can affect emission rates significantly. A material's history includes packaging (i.e., whether or not the material was tightly packed), temperature, humidity, and chemistry of the environment(s) it was exposed to. Therefore the history of a material must also be considered when interpreting emission data.

4. Surface area of a material relative to the floor area or volume of a space. The surface area of a material provides an indication of the amount of exposed material present in an indoor environment. [The ratio of the surface area of a material divided by the volume of the space where it is installed is defined as the **loading factor** or **product loading** (ASTM, 1990a)]. Levin (1989) suggests comparing the surface area of a material to that of the floor. In the case of floor coverings, the exposed area is 100 percent of the floor area, whereas in the case of T-bar suspended ceiling tiles in which both sides are exposed to indoor air, the percentage approaches 160 percent (Tshudy, 1995). The exposed area of work-station panels could range up to 350 percent of the floor area depending on occupant density and panel height.

5. Environmental factors such as temperature, humidity, and ventilation rate. In general, emission rates of products increase with temperature. Air movement and ventilation does not increase emission rates resulting from diffusion-dominated processes within dry materials such as carpets, but does affect emission rates resulting from surface-dominated processes of wet products such as paints in the early drying stage. The following section addresses the effect of increased ventilation on VOC emission rates and indoor air concentrations.

Reduction of VOCs from building materials may involve one or more of the above-listed factors. Material conditioning involves varying environmental factors such as increasing ventilation rates (see Section 2.5 for development of ventilation protocols) or temperatures (see Section 3.3 and Appendix D for a description of a process known as building "bake-out"). Material conditioning, although not always a practical solution, can be done at the manufacturing or assembly site, at a bonded storage facility, or after installation and before building occupancy (see Section 2.3 for development of material-conditioning protocols). Note that storage of certain materials after manufacturing is unavoidable especially in cases of special production orders or large quantities. A conditioning process for materials with slow-decaying emission rates must always be considered prior to installation.

1.5.4 Effect of Increased Ventilation on VOC Emission Rates and Indoor VOC Concentrations

VOC emission rates and ventilation rates affect the resulting indoor concentration from any indoor VOC source. Obviously, the stronger the source the more ventilation is needed to lower VOC concentrations. For example, Tichenor (1987) reported that for a caulking compound, total volatile compound (TVOC) emissions (i.e., sum of air concentrations of individual VOCs) in a small environmental chamber were insignificant after 6 hr at an air change rate of 1.8 air changes per hour (ACH). However at 0.36 ACH, significant emissions were measured 10 hr after application and emission rates were declining very slowly. Tichenor also reported that for a given source there can be differences in emission rates for individual compounds. For example in the case of caulking at 0.36 ACH, the emission rate of one compound (i.e., C4 ketone) decreased much faster than the rates of two other compounds (i.e., C8 alcohol and C7 ester) (Tichenor, 1987). In another study, Tichenor and Guo (1991) reported that: (a) the VOC emission rates of wood stain and polyurethane, respectively, increased when the ventilation rate was increased from 0.35 to 4.6 ACH and from 0.5 to 2.0 ACH; and (b) the VOC emission rates from floor wax were unaffected by increasing the ventilation rate from 0.25 to 2.0 ACH.

However, there is a limitation on the effect of ventilation in reducing indoor VOC concentrations. For example, Gunnarsen et al. (1993) reported that emission rates of water-based acrylic paint applied on both sides of an aluminum plate in a chamber increased with increasing ventilation rates up to approximately 1.8 $ft^3/min \cdot ft^2$ (9 $L/s \cdot m^2$) floor. Further increase of the chamber's ventilation rate did not increase the emission rate of the paint. (Note that paint application is an evaporation-controlled process.) The authors also reported that emission rates of two other test samples (i.e., linoleum and silicone-based sealant) increased with increasing ventilation rates up to approximately 0.05 $ft^3/min \cdot ft^2$ (0.25 $L/s \cdot m^2$) and that there were no further increases in the emission rates of these test samples at higher ventilation rates.

Finally, indoor VOC concentrations may fluctuate when building and local ventilation rates vary as in the case of variable air volume (VAV) systems. These systems vary not only the amount of outdoor air supplied to a building, depending on the outdoor air conditions (i.e., temperature and humidity), but also vary the amount of supply air to various zones served by VAV boxes (i.e., local ventilation) in response to the thermal requirements of individual zones. As a result, indoor concentrations of building-related VOCs fluctuate in these buildings depending on building and local ventilation rates.

The reader is referred to Section 2.5 for guidance on using ventilation to reduce indoor exposures to VOCs and other contaminants. Section 2.5 also discusses factors that may limit the amount of ventilation that can be provided to a building.

1.6 Low-VOC-Impact Building Materials and Products

Low-VOC-impact building materials or products may be defined as those that, when installed in a building, result in minimal or reduced exposure of occupants to VOCs that are emitted from these materials or products. Although ambiguous, this definition may prove to be a useful concept. Currently there are very few specific VOC guidelines that a material or product must meet to be classified as low-emitting. Instead, continuous development of new building materials and products that emit less VOCs than similar materials and products on the market is encouraged based on available technology.

Even so-called **no-VOC emitting products** (sometimes also referred to as **zero-VOC emitting products**) can emit VOCs. This is because for the purposes of measuring the VOC content of paints and related coatings, the USEPA, the American Society for Testing and Materials (ASTM), and the California Air Resources Board (CARB) define **reactive VOCs** as "any compound of carbon,...which participates in atmospheric photochemical reactions." (USEPA, 1983; ASTM, 1993; CARB, 1993a). (The complete definition of reactive VOCs is shown in the glossary at the end of this document.) Therefore "no"-VOC emitting products may emit other VOCs, such as methylene chloride, that could cause human health effects. In California "no"-VOC and "low"-VOC emitting architectural coatings and consumer products generally have lower VOC contents than other similar products sold outside the state. This is because state and regional regulations limit the amount of reactive VOCs in various categories of coatings and products sold and used in California. These regulations are discussed further in Appendix H.

Several factors determine whether or not a building material has a low VOC impact. The most important factors are discussed below.

1. <u>Amount and chemical composition of emissions</u>: The amount and chemical composition of emissions from an indoor building material can help determine whether or not exposed occupants will experience health effects or odors. Materials that emit carcinogenic compounds or chemicals known to have reproductive or developmental effects should be discouraged especially if their use results in exposure levels exceeding the California Proposition 65 (1994) No Significant Risk Levels.

2. <u>Occupant exposure</u>: In addition to the emission rate of an indoor building material, VOC exposure depends on the building's ventilation rate, the proximity of the material to the occupants, the amount of material, the duration of the occupants' exposure, and the local air distribution pattern. Total exposure decreases with distance from a source and increases with longer exposure time. For example, emissions from workstations in the immediate proximity of office workers may result in high occupant exposures to VOCs during an 8-hr workday. In contrast, emissions from a remote source, such as duct and ceiling insulation, may result in lower occupant exposure to VOCs assuming good air mixing.

1.7 Costs Associated With the Reduction of Occupant Exposure to VOCs From Building Materials

Building owners may be reluctant to expend more money to minimize occupant exposure to VOCs unless information on the benefits of such measures is available or can be obtained with some reliability. Such benefits include increased productivity, decreased health care costs, improved building marketability, and reduced liability exposure. Design and building professionals should be prepared not only to justify but also to estimate the costs, if any, of measures to reduce occupant exposure to VOCs. Unfortunately, very little information is available in this area. Following is a discussion of these costs.

1. <u>Cost of building materials</u>: Building materials account for a large percentage of typical construction costs. Levin and Hodgson (1994) reported that this percentage is between 30 and 60 percent of the construction costs. Typically the price of building materials is independent of emissions characteristics. Although small premiums may be charged for some low-VOC-emitting materials, such as in the case of low-VOC-emitting paints, these premiums are likely to be reduced or eliminated as demand for these products increases. In the case of paints, more stringent ambient air regulations are likely also to result in reduction of these premiums. In addition, group purchases through building consortiums such as industry groups and school districts can reduce these premiums even further.

2. <u>Emissions testing of building materials</u>: For a typical product, the cost for VOC emissions testing varies depending on the sampling technique used (i.e., headspace, small or large-size chamber), duration of the test, number of test ventilation rates, and number and type of the chemical analyses. Levin and Hodgson (1994) reported that the cost of testing individual products based on the dynamic "headspace" sampling technique (see Item 4 of Section 2.2.2 for a description of emissions testing procedures) ranges between $1,000 to $2,000 per test. The cost of testing large-size products requiring environmental chambers, varies from between $400 and $1,500, such as in the case of testing particleboard and medium density fiberboard (MDF) for formaldehyde emissions (Groah and Margosian, 1995), to more than $5,000, such as in the case of testing complete office workstations for TVOCs. In addition to the cost of laboratory testing, other costs, such as the cost of shipping a product or material from the manufacturing site to the testing laboratory, also must be considered. Shipping costs, especially in the case of complete workstations, are not trivial. Also very few commercial laboratories are equipped with large-size chambers that are capable of performing long-term testing of samples. The cost of emissions testing is usually a small fraction of the purchase cost of a material on a single project (i.e., 0.1 to 1 percent of the purchase cost). The cost of emissions testing, and re-testing if necessary, is normally borne by the manufacturer as part of their product research and development. The larger the size of a project, the more vendors will tend to cooperate in providing VOC-related information, especially if such a requirement is included in the contract document specifications, i.e., product manufacturers may be more willing to provide emissions test data, on larger jobs than on smaller ones (see Appendix F for an example of contract document language). Also in the case of large corporations with multiple construction projects, a single strategy on emissions testing and selection of building materials could be applicable to other projects with similar design specifications.

   A number of manufacturers have already tested their products and may be willing to provide their results for review at no additional cost. However, some manufacturers may be reluctant to provide these data for a number of reasons such as: (a) concern that emission data, obtained under chamber conditions, may be misleading, inaccurate, and not representative on how their products actually impact indoor air quality under actual use conditions (such as in the case of carpet adhesives where another product is always installed over them); (b) confidentiality; (c) potential liability exposure; and (d) concern on how the data may be "misused" (Tshudy, 1995).

3. Design fees: The design team consists not only of an architect and a mechanical engineer, but of other professionals who may be involved with various aspects of the overall design for improved indoor air quality including an interior designer, a cost estimator, a specification writer, an IAQ consultant, and an acoustical consultant. The total design fee for improved indoor air quality includes, among others, selection of low-VOC-impact building materials and design and commissioning of the HVAC system(s) and, as such, it is based on the design team's total time and not on the quantity of materials purchased or size of the building. However, the total design time depends on various other factors such variety of materials used in a project, time needed for researching and obtaining product information, the project's complexity, etc.

   Because the task of selecting low-VOC-impact building materials and products is a new area for most Architectural/Engineering (A/E) firms, very little published information exists on the increased design fees associated with this task. For example, Bernheim (1993, 1995a) reported that the total estimated indoor air quality design fee (including not only material evaluation and selection, but also engineering time for HVAC commissioning) for a 391,000-ft^2 (36,325-m^2) library in California was 1.08 percent of the A/E fees. It is noted that Bernheim's reported costs are based on only one project and therefore is insufficient to draw any general conclusions about design fees.

4. Increased ventilation: The energy costs associated with increased ventilation may not be prohibitive as indicated by Eto and Meyer (1988) who calculated the energy costs resulting from increasing ventilation rates from 5 to 20 ft^3/min per person. The authors reported that annual energy costs increased by as little as 1 percent to as much as 8 percent for heating and from less than 1 to 14 percent for cooling. Although the increased energy costs of a building **flush-out** (i.e., a process during which a building is continuously ventilated for several days or weeks at the maximum possible outdoor air rate) are likely to be higher than those reported by Eto and Meyer (1988), they are unlikely to be prohibitive. The party responsible for the increased energy cost of ventilation during construction and building flush-out before occupancy must be identified early in the design and planning phases of a building.

5. Other costs: Other costs, such as material conditioning, delayed occupancy, and HVAC commissioning, also must be considered. These costs vary widely among projects and should be considered in the early stages of a building's design. No data exist on the costs of material conditioning and delayed occupancy. However, some very limited data is available on costs of HVAC commissioning. The average cost of commissioning a new office building is 2 to 5 percent of the installed equipment to be commissioned, and the cost of operating a commissioned building is 8 to 20 percent less than a similar non-commissioned building (Lawson, 1996). In addition, owners of buildings that have not been commissioned could lose \$4 to \$8 per ft^2 each year "...due to faulty design or installation of HVAC systems" (Lawson, 1996). However, the entire building commissioning procedure may not be appropriate or necessary in all projects, thus reducing the commissioning cost to about 1 percent of the mechanical systems cost (Bernheim, 1995b).

   Finally, it should be noted that local utility companies in certain areas offer incentives for lowering on-peak loads and for HVAC commissioning thus reducing owner's out-of-pocket expenses for building commissioning.

In summary, the limited information presented above indicates that the highest cost of reducing occupant exposure to VOCs is associated with emissions testing of building materials, especially when many products must be tested. However, design fees and costs of building materials, increased ventilation, and other costs must be considered during the project-planning phase. In most cases, costs other than emissions testing and design fees are project specific. For example, the cost of product reformulation may, in certain cases, exceed all other costs. However, improved marketability of that product may justify a manufacturer's cost of reformulation. Costs of testing and product reformulation should be borne by the manufacturer as part of their product research and development and should not be passed directly to the consumer. It is important to realize that the costs of reducing occupant exposure to VOCs can be justified on the basis of increased employee productivity, reduced health care costs, increased building marketability, and reduced liability exposure. A **life cycle** cost analysis enables a user to compare possible higher initial costs, if any, to reduced long term costs for the anticipated life of a product or material.

SECTION 2. GUIDELINES

2.1 The Recommended Strategy to Reduce Exposure to VOCs

The guidelines presented in this section consist of a five-step approach to reduce exposure to VOCs from building materials and products. The recommended approach must be included in the design phase of a building. The reader is referred to the related sections for a detailed discussion of each topic.

1. Evaluate and select low-VOC-impact building materials and products (Section 2.2).

2. Pre-condition materials to minimize VOC emissions after installation (Section 2.3).

3. Install building materials and products based on their VOC emission decay rates (Section 2.4).

4. Ventilate during and after installation of new materials and products (Section 2.5).

5. Delay occupancy until VOC concentrations have been reduced substantially (Section 2.6).

2.2 Evaluation and Selection of Low-VOC-Impact Building Materials

Evaluation and selection of low-VOC-impact building materials is the first step in minimizing occupant exposure to VOCs. The procedure described here is equally applicable for new construction, renovation, remodeling, and refurbishing. It is imperative that design professionals, as well as building owners and managers responsible for building material selection, understand: (a) the impact of building materials on the quality of indoor air; and (b) the importance of selecting low-VOC-impact building materials and products. Figure 3 summarizes the four-step strategy for evaluating and selecting low-VOC-impact building materials and products. Sections 2.2.1 through 2.2.4 discuss each of these steps in detail.

2.2.1 Step 1 - Identification of Target Building Materials and Products

In general, wet-applied products, such as adhesives, paints, caulks, sealants, and finishes, dry quickly (typically in few hours or days) and have high emissions of short durations (typically a few hours). Other products, such as particleboard and plywood, have low emissions lasting long time periods (typically a few months or years). However some wet products, such as carpet adhesives, have long-term emission rates that are significantly higher than many dry products.

Factors other than emission rates also need to be considered when choosing building materials and products. The most important of these factors are described below.

1. Quantities of the materials used: Because selection of a material depends on its installed quantity, it is important to identify the quantities of all VOC-emitting materials. Materials used in large quantities may be of concern even if they are low-emitting.

   As described earlier, Levin (1989) suggested comparing the surface area of a material to that of the floor. In the case of floor coverings, the exposed area is 100 percent of the floor area, whereas in the case of T-bar suspended ceiling tiles in which both sides are exposed to indoor air, the percentage approaches 160 percent (Tshudy, 1995). Openings in the T-bar ceiling, such as light

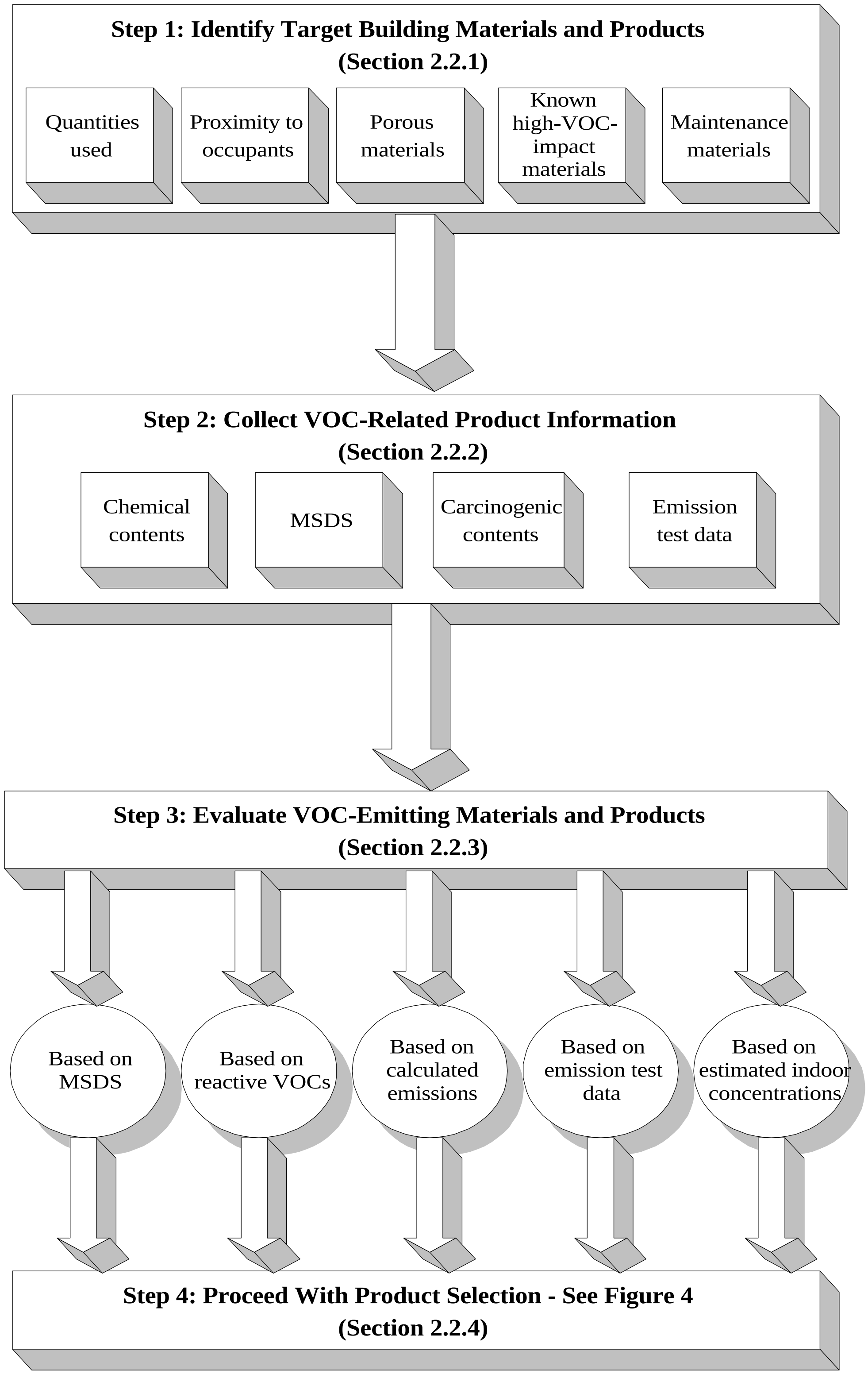

Figure 3. Four-Step Strategy for Evaluating and Selecting Building Materials and Products

fixtures and ventilation registers must be taken into consideration when calculating percentage of ceiling exposed area. The exposed area of work-station panels range up to 350 percent of the floor area depending on occupant density and panel height (Levin, 1989). Materials with high loading factors (i.e., surface area of installed material divided by the volume or floor area of the indoor environment where the material is installed) are of particular interest due to the amounts of these materials present in indoor environments.

2. Proximity of a material to occupants, such as in the case of work stations and interior partitions: Exposure of occupants to VOCs emitted from a material increases as the distance between the material and the occupants decreases. Exposure of occupants also depends on the degree of air mixing in the occupied space. For example, if the supply air short-circuits to the return opening before mixing with the room air then VOC concentrations will be higher in the occupied space than would have been if supply air mixed thoroughly with the room air before it was exhausted.

3. "Porous" materials: Identification of these materials is important because they act as "sinks" adsorbing and re-emitting VOCs originating from other sources (see Section 1.5.1 for a description of the characteristics of VOC sinks). Porous materials include carpets, acoustic and thermal insulation materials, and fabric-covered partitions.

4. Known high-VOC-impact materials: Known high-VOC materials can be identified using existing knowledge on product emissions. Because of the continuous development of new, lower VOC-emitting materials and products, it is important that current emission data be used for this evaluation. Use of known high-VOC emitters should be avoided.

5. Maintenance products used, such as waxes, polishes, disinfectants, and cleaners associated with target building materials: Although not part of the construction process, the use of such products is directly associated with the installed materials. For example, installation of sheet vinyl flooring requires more frequent maintenance with chemical-containing materials such as cleaning and waxing products than other floor coverings such as ceramic tile or hardwood.

2.2.2 Step 2 - Collection of VOC-Related Product Information

The extent of the collection process of VOC-related product information relates to the scope and size of a project. Manufacturers may be reluctant to provide some of the VOC-related product information but recently, due to an increased awareness of the importance of good indoor air quality among design professionals, more building product manufacturers have their products tested and thus information is increasingly available. Some product manufacturers, such as carpet, particleboard, medium density fiberboard (MDF), and plywood manufacturers, have already initiated voluntary testing programs (see Appendix C for descriptions of various labeling programs). Obviously the extent of product testing depends on the scope and size of a project.

The following information should be collected from product manufacturers.

1. Copies of MSDSs (Material Safety Data Sheets): MSDSs should be obtained for each material or product used. Secondary suppliers and manufacturers should also be asked to provide these lists. (See Section 2.2.3.1 for a description of information that can be obtained from MSDSs).

2. Product specifications: Product specifications usually include lists of chemical contents. However, availability of information on chemical contents is highly variable throughout the industry. Some manufacturers even consider this information proprietary and may be unwilling to release it, whereas

others provide related information in their published literature. It is unreasonable to expect architects or other building designers to conduct the necessary literature review for collection of such information.

It is noted that delivered products may not have the same chemical contents as those published by the manufacturer. This is because chemical contents may change due to manufacturing variations, batch-to-batch variations in product formulation, and variations in curing time. One way of ensuring that delivered and tested products have the same chemical composition as those tested and reported is to require that the manufacturer provides an appropriate certificate. Note that it is common practice for manufacturers to issue certificates for other product characteristics, such as pile height in the case of carpets, in order to assure a customer that the delivered product will have the same characteristics as the display sample.

3. <u>Emissions testing data</u>: VOCs can be measured either individually or collectively as TVOCs. Results can be presented either as emission factors or total emissions from the time a product is installed until it is completely dry.

   Testing of a product for emissions can be conducted either in an environmental chamber or from a "headspace" apparatus. <u>Environmental chamber testing</u> is conducted in small-size chambers [e.g., 1 L or less (ASTM, 1990a)], in medium-size chambers (i.e., few liters to 5 m^3), or in large-size chambers (i.e., above 5 m^3) capable of accommodating full-scale samples (e.g. office furniture). Large-size chambers are expensive to build and operate. In contrast, <u>headspace testing</u> involves placing a product <u>sample</u> (e.g., a section from a carpet roll, a piece of plywood, etc.) in a closed container for a pre-determined period of time and then sampling the air in the "head space" above the sample in the container. Both static (i.e., closed container) and dynamic (i.e., air flowing through the container) headspace analyses are used. The reader is referred to the ASTM Standard Guide D 5116 - 90 (ASTM, 1990a) for more information on available techniques for measuring VOC emissions from building materials using small-scale environmental chambers.

   Reporting of emission testing results should include (see Appendix F for a sample of contract language incorporating most of the items listed below):

   a) emission factors of TVOCs and any individual VOCs of special concern due to their toxicity or irritability, such as formaldehyde;

   b) time and history since product manufacturing or product installation when samples were taken;

   c) test and environmental conditions such as sample preparation details, analytical methods, amount of ventilation, temperature, relative humidity, and air velocities; and

   d) product loading factor, i.e., exposed surface area of the material tested in relation to chamber's volume or floor area.

   Standard testing methods exist for some products and materials [e.g., ASTM E 1333 - 90: *Standard Test Method for Determining Formaldehyde Levels from Pressed Wood Products Under Defined Test Conditions Using a Large Chamber* (ASTM, 1990b).] Appendix G lists a survey of existing test methods. A number of standard test methods are now being developed and should become available in the next few years. Drafts of proposed test methods may be included in contract proposals for some construction projects (e.g., see Appendix F for an example of a contract document language). It is important to ensure that the product tested is the same product that is installed in the building. This can be achieved by incorporating appropriate certification language in the contract documents. Note that it is common practice for manufacturers to issue certificates for other product characteristics, such as pile height in the case of carpets, in order to assure a customer that the delivered product will have the same characteristics as the display sample.

VOC-related information also should be collected for all cleaning products associated with target building materials as described above.

4. Other sources: These may include lists of any known or suspected carcinogens or reproductive or developmental toxicants: Product manufacturers should identify any VOCs that are known or suspected carcinogens or reproductive or developmental toxicants, as listed by the State of California (California Proposition 65, 1994; CARB, 1993b) and the International Agency for Research on Cancer (IARC) as published by WHO in the *IARC Monograms on the Evaluation of Carcinogenic Risks to Humans* (IARC, 1987, 1989, or most recent edition). Materials that emit carcinogenic compounds or chemicals known to have reproductive or developmental effects should be discouraged especially if their use results in exposure levels exceeding the California Proposition 65 No Significant Risk Levels. (Table E8 of Appendix E identifies some of the most common VOCs emitted from building materials that are on the Proposition 65 list and/or the IARC list.) Formaldehyde should be reported and listed separately.

2.2.3 Step 3 - Evaluation of VOC-Emitting Products

Building products can be evaluated based on: (a) MSDSs; (b) reactive VOCs; (c) calculated chemical emissions using vapor pressures and mass transfer coefficients; and (d) results of emissions testing. These four evaluation methods are discussed next.

2.2.3.1 Evaluation of Building Products Based on MSDSs.

MSDSs are documents mandated by the OSHA in Section 1910.1200(g)5 of Title 29 of the Code of Federal Regulations (CFR) (1994) and by the California Occupational Safety and Health Administration (Cal-OSHA) in Section 5194(g) of Title 8 of the California Code of Regulations (CCR) (1994) for all types of work environments. The purpose of an MSDS is to list all **hazardous substances** contained in a specific product. Cal-OSHA defines a hazardous substance as "any substance which is a physical hazard or a health hazard or is included in the List of Hazardous Substances prepared by the Director pursuant to Labor Code section 6382" (CCR, 1994). Furthermore, Cal-OSHA defines **health hazard** as "a substance for which there is statistically significant evidence based on at least one study conducted in accordance with established scientific principles that acute or chronic health effects may occur in exposed employees." Included in this category are "...substances which are carcinogens, toxic or highly toxic agents, reproductive toxins, irritants, corrosives, sensitizers, hepatotoxins, nephrotoxins, agents which act on the hematopoietic system, and agents which damage the lungs, skin, eyes, or mucous membranes" (CCR, 1994).

MSDSs are available for most building products and employees must have access to MSDSs for each hazardous substance-containing product if the amount of product they use exceeds the amount that a person would typically use at home. For example, an office worker is not required to have an MSDS for a household cleaning product such as window cleaning detergent if the worker uses this product to clean the inside of his/her office windows once a month, a use comparable to a typical home use of this product. However, a building janitor who uses several gallons of the same window detergent each day must have access to these documents. During building construction, MSDSs must be accessible to workers that are potentially exposed to materials and products which contain hazardous substances. Products deemed as "articles" such as curtains do not need to have MSDSs.

An MSDS is organized into various sections, each section providing information in a specific safety area. The following list offers section-by-section guidance on the uses and limitations of MSDSs.

1. Components: This section identifies hazardous substances contained in a product. If the hazardous substance is a mixture that has not been tested as a whole then the following are listed.

   a. The names of all ingredients that: (i) have been determined to be health hazards; and (ii) comprise 1 percent or greater of the composition. Substances identified as carcinogens are listed if concentrations are 0.1 percent or greater. However, ingredients comprising 1 percent or less of a mixture's composition, or carcinogens comprising less than 0.1 percent of this composition, are listed if there is evidence that ingredients could be released from the mixture in concentrations exceeding established OSHA Permissible Exposure Limits (PELs), ACGIH Threshold Limit Values (TLVs), or could present a health hazard to employees.

   b. The names of all ingredients that have been determined to present a physical hazard when present in the mixture.

   Some hazardous substances may be listed as proprietary and thus information on their compositions are not disclosed and are protected as trade secrets (e.g., see Section 1.5.3; Item 1; first example). However, information on the properties and effects of substances covered under trade secrets must be disclosed. Also byproducts unknowingly formed during the manufacturing or installation process may not be listed. In addition, some MSDSs: (a) list percentage ranges of the contents and in some cases these ranges are fairly large; and (b) list contents of several products having similar hazards and mixture contents with specific chemical composition varying from mixture to mixture. Finally MSDSs do not cover variations in the manufacturing process, batch-to-batch variations in formulation, and variations in curing, packaging, storage, and transportation.

2. Emergency and First Aid Procedures: The emergency and first aid instructions listed under this section are applicable to high-level, worst-case exposures, such as in the case of spills, and not to the exposures resulting from intended use of the product.

3. Health Hazard Effects: This section lists health effects based on animal and human studies. The listed carcinogenic effects are primarily due to exposure of experimental animals to concentrations that are much higher than those typical of office environments. In addition, acute and chronic health effects for high-concentration exposure are listed if known. Nuisance effects also may be listed if known.

4. Physical Data: This section provides information on odor, volatility, and reactivity. The listed odor descriptions may be useful in identifying sources; the listed volatility information (i.e., boiling point, flash point, vapor pressure, vapor density, evaporation rate, etc.) as well as stability may suggest which substances are likely to become airborne; and reactivity information may be useful in determining compatibility with other chemicals. However, interpretation of physical data to predict indoor concentrations is difficult because of lack of information on the diffusion characteristics of building materials (see Section 2.2.3.3: Evaluation of Building Products Based on Calculation of Chemical Emissions for more information on this topic).

5. Fire Fighting Measures: This section describes expected combustion products in the event of a fire. This information may be useful in the development of fire safety procedures.

6. Hazardous Reactivity Data: The hazardous reactivity data listed in this section may be useful for developing proper storage and installation procedures for a product or material. In addition, compatibility with other chemicals may be determined from the listed data.

7. Handling, Storage, and Spill Control Measures: The information on proper storage, transportation, and packaging procedures listed in this section may not be applicable to office environments where chemicals are used in smaller quantities than in industrial environments. Cleaning procedures and protective measures in the event of spills and leaks also are identified in this section. However, controls for reducing emissions from indoor use of a product or material are not specified in this section.

However, some caution should be exercised in the use of MSDSs because sometimes they are incomplete or inaccurate, failing to list all potentially hazardous substances. Kolp et al. (1995) reported that of the 150 MSDSs they evaluated for accuracy and completeness they found that: (a) 89 percent provided "identifiable chemical names"; (b) only 37 percent had accurate health effects data with acute data being more correct than chronic; (c) 76 percent provided "adequate first-aid information"; and (d) only 47 percent were "judged to have an accurate information for personal protective equipment."

2.2.3.2 Evaluation of Building Products Based on Reactive VOCs.

Architectural coatings, aerosol coatings, and certain categories of consumer products, including cleaning products, can be evaluated based on their **reactive VOC** content. However, caution must be exercised when using such data. As was mentioned in Section 1.6, the USEPA, the ASTM, and the CARB define reactive VOCs as those VOCs that "participate in atmospheric photochemical reactions" (see glossary at the end of this document for complete definition). However some indoor VOCs, such as methylene chloride, are excluded from the definition of reactive VOCs. In addition, manufacturers of building materials other than the ones listed above, such as carpet and office furniture, are not required to supply such information.

In California, the CARB, the local air quality management districts (AQMDs), and the air pollution control districts (APCDs) regulate the maximum amount of reactive VOCs contained in architectural coatings, aerosol sprays and consumer products. Therefore products sold and used in California to build, decorate, maintain, and clean office buildings must meet at least the applicable state and local regulations on reactive VOCs. Appendix H gives a summary of background information on these regulations and lists the maximum allowable quantities of reactive VOCs for selected product categories.

2.2.3.3 Evaluation of Building Products Based on Calculation of Chemical Emissions

Calculation of emission rates based on vapor pressures and mass transfer coefficients for chemicals of concern is theoretically possible and can be made based on the following equation (ASTM, 1990a).

$$E = K_m (VP_s - VP_a) \tag{1}$$

where:
E = emission rate
K_m = mass transfer coefficient
VP_s = vapor pressure at the surface of the material
VP_a = vapor pressure in the air above the surface of the material

However, such calculation requires knowledge of the diffusion characteristics of the material. For example, in the case of carpet containing 4-PC an odorous compound, the diffusion characteristics of 4-PC in the carpet must be known. In the case of wet products, a film develops shortly after application and therefore knowledge of the film's characteristics is important. Another problem associated with using Equation 1 is that it requires knowledge of the chemical contents of a product or a material. Unfortunately accurate information on the chemical contents of a product may be difficult to obtain. For example, MSDSs may be incomplete or not accurate enough for such calculations.

Both empirical and fundamental mass transfer models are being developed to predict emission rates of building materials. It is beyond the scope of the guidelines presented in this document to discuss these complex diffusion-based mass-transfer models. Instead, the interested reader is referred to Tichenor et al. (1993), Clausen et al. (1993), Little et al. (1994), and Tichenor (1995).

2.2.3.4 Evaluation of Building Products Based on Emissions Testing

Emissions testing data can be used to compare functionally equivalent materials or products. However, such a comparison must be done carefully keeping in mind the following.

1. There are no standard testing and reporting methods for TVOCs. A number of researchers reported the following:

   (a) Hodgson (1995) reported that TVOC results for the same mixture of compounds analyzed by different methods can easily vary by a factor of two or more and that reported TVOC results from laboratories analyzing the same TVOC mixture and using the same analytical instrumentation methods may vary due to differences in: (i) sample collection methods; (ii) TVOC calibration methods; and (iii) data reduction and analysis. Hodgson also reported that the accuracy of TVOC results depends on the mixture of compounds and that not a single analysis method is appropriate or sensitive for all VOCs.

   (b) Brown et al. (1994) in a review of concentration of VOCs in indoor air noted the lack of consistency among investigators in the definition of TVOC; and

   (c) Colombo et al. (1993) and DeBortoli et al. (1995) demonstrated in two separate comparisons of 20 laboratories that large variations existed among these laboratories in reported TVOC measurements for a selected number of building materials.

   Therefore TVOC emission factors should be used to compare <u>similar products</u> emitting <u>similar VOCs</u> that have been tested using the <u>same</u> methods.

2. Age and condition of tested materials may vary. Typically, older materials have lower emission rates than newer materials.

3. The environmental conditions of a test chamber (i.e., temperature, humidity, ventilation rate, and air velocities), the size of a test chamber, and the adsorption characteristics of a chamber can affect the reported emission factors. For example, Hodgson et al. (1993) measured VOCs emitted from four carpet samples both in small-volume (i.e., 4-L) chambers and in a large-volume (i.e., 20-m^3) environmental chamber and reported the following:

   a) the concentrations of the "least volatile compounds" measured, i.e., 4-PC and butylated hydroxytoluene (BHT), were two to three times lower in the small-volume chambers; and

b) the concentrations of some "relatively volatile compounds", such as 4-ethenylcyclohexene, styrene, and hexamethylcyclotrisiloxane, were one order of magnitude lower in the small-volume chambers.

4. VOC emissions from tested products may differ from those delivered for installation, due to a number of reasons including variations in manufacturing process, batch-to-batch variations in formulation, and variations in curing, packaging, storage, and transportation.

Table E1 of Appendix E lists a suggested classification scheme for selected building materials. Levin (1995b, 1996) reported that published data indicate that in most buildings, building-wide average TVOC source strengths (i.e., emission factors calculated from measured TVOC concentrations and building ventilation rates) typically range from about 500 to 1,500 $\mu g/m^2 \cdot hr$. Levin also reported that in "clean" buildings, published TVOC source strengths are well below 500 $\mu g/m^2 \cdot hr$, whereas, in other "less clean" buildings, published source strengths are between 2,000 and 10,000 $\mu g/m^2 \cdot hr$. A study conducted in 56 office buildings in nine European countries reported that the "total mean chemical pollution load" (i.e., emission factor) was 1080 $\mu g/m^2 \cdot hr$ (Bluyssen et al., 1995a, 1995b)

It is desirable that materials and products have VOC emission data. The use of materials and products without such data should be discouraged. Emission data can be obtained by submitting samples to reputable laboratories for testing (see Section 1.7 for typical costs of emissions testing).

2.2.3.4.1 Prediction of Indoor VOC Concentrations Based on Emissions Data

Prediction of indoor VOC concentrations can be based on emissions data and building ventilation rates. One of the primary advantages of this method is that indoor VOC concentrations can be predicted for various materials and products before construction, thus avoiding chemical sampling and possible expensive mitigation (Alevantis and Petreas, 1995). Once all the building parameters are entered in the computer, a designer can choose various alternatives and calculate immediately the resulting indoor concentrations. However, such predictions are complicated for the following reasons:

a) prediction of product emissions over periods of several months based on extrapolation of emissions data collected under controlled conditions over a few hours or days may not be accurate because emissions may not decay at a constant rate; and

b) the effect of all potential sinks within a building is difficult to estimate.

Mason et al. (1995) reported that a modeling effort in one building failed to predict actual building concentrations. For these reasons, quantitative prediction of indoor VOC concentrations based on emissions data may not be practical for widespread use in the field. At the present time such models exist and are used primarily in research and experimental studies [e.g., Sparks et al. (1989, 1991); Sparks and Tucker (1990); Walton (1994); Tichenor et al. (1991); Axley (1991)]. However, estimates of VOC concentrations based on emission data and simplified models can be useful for range-finding purposes during material and product selection process. See Appendix I for a simplified method of estimating indoor concentrations from emission factors.

2.2.3.4.2 Evaluation of Materials and Products Based on Indoor VOC Concentrations

Evaluation of materials and products based on VOC concentrations requires expertise in chemistry, material sciences, toxicology, and medicine. Because there is limited data available in these fields, assistance of consultants may be needed to interpret and compare data from competing manufacturers. See Appendix I for two examples of product comparisons based on predicted indoor VOC concentrations. The information in the following appendices can be used to interpret emission factors.

1. Appendix E: This appendix discusses the following:

   a) Guidelines for TVOCs: Section E1 discusses the European guidelines, Tucker's classification scheme of building materials, and the State of Washington's requirements. As was stated previously in Section 2.2.3.4 (Item 1) the TVOC concept should be used only as a screening tool to determine whether or not VOC concentrations in buildings are within a typical range. See the end of this section for reported "typical" TVOC concentrations.

   b) Health effects of selected VOCs: At this time the relation of TVOCs to health effects is highly controversial. Until more studies are conducted to clearly define this relation, it appears that a more rational approach is to rely on specifically identified VOCs whose health effects are known. Section E2 discusses the sources, exposure routes, health effects including short-term exposure thresholds, and any applicable guidelines for six selected VOCs. The VOCs discussed are benzene, formaldehyde, methylene chloride, styrene, tetrachloroethylene, and toluene and were selected because: (a) they are common indoor air contaminants; (b) they are listed by the CARB as toxic air contaminants (CARB, 1993b); and (c) they have significant adverse health effects.

   c) Carcinogen and Reproductive Toxicants: Section E3 lists those VOCs known or suspected to be emitted from building materials presented in Appendix B, that are also listed by Proposition 65, the IARC, or the CARB.

   d) Sensory effects of VOCs: Section E4 discusses the odor and irritant effects of VOCs and lists odor thresholds and irritation characteristics for 58 VOCs that can be emitted from building materials and products presented in Appendix B. (See Section K9 of Appendix K for additional sources of information on chemical irritants and toxicants.)

2. Appendix C: This appendix provides a survey of existing product labeling programs in the United States (including the CRI's labeling program and the Hardwood Plywood and Veneer Association's as well as the National Particleboard Association's formaldehyde labeling programs) and in Europe. The VOC requirements that must be met in some of these programs are also listed.

Several studies have reported TVOC concentrations in occupied office buildings. The results of some of these studies are listed below in order to assist the reader in interpreting these concentrations.

1. Wallace et al. (1991) reported that TVOC concentrations in 10 buildings (three of which were new) in several U.S. cities were between 1,000 μg/m^3 and 42,000 μg/m^3 with a geometric mean of 2,300 μg/m^3 (the highest TVOC concentrations were measured in the three new buildings).

2. Daisey et al. (1994) reported that TVOC concentrations in twelve occupied California office buildings ranged from 230 to 7,000 μg/m^3 with a geometric mean of 510 μg/m^3 (the highest TVOC concentrations were measured in two buildings with wet-process copiers; the geometric mean excluding these two buildings was 410 μg/m^3).

3. Bluyssen et al. (1995a) and Bernhard et al. (1995) reported that building-average TVOC concentrations in 56 office buildings in nine European countries ranged between 40 and 1,840 μg/m^3 with a geometric mean of 230 μg/m^3.

4. An ongoing cross-sectional study of public and commercial occupied office buildings is being

conducted by the USEPA (Womble et al., 1995; Girman et al., 1995; Brightman et al., 1996). In this Building Assessment Survey and Evaluation (BASE) study, TVOC measurements are being collected. TVOC measurements are measured in three sites at each building with each site having a target population of 50 occupants and no more than two air handling units. Brightman et al. (1996) reported that TVOC concentrations in 16 buildings ranged from 33 to 515 µg/m^3 with the exception of one building in which TVOC concentrations were as high as 2108 µg/m^3 due to high dichlorodifluoromethane concentrations. Table 2 lists the results for each test site.

The results of the above studies can be used as a guide in interpreting TVOC concentrations. The reader is reminded that TVOC concentrations should be used as a screening tool to determine whether or not building TVOC concentrations are within "typical" ranges. Levin (1996) suggested that indoor TVOC concentration of occupied buildings, other than new on newly renovated, exceeding 1,500 µg/m^3 "suggest the need for investigation of sources and mitigation."

Table 2. TVOCs Concentrations for 16 Large Buildings Measured Under the USEPA's BASE Study Using EPA TO-14 Standard Testing Method (Brightman et al., 1996)

Building ID	TVOC Concentration, µg/m³				
	Indoor			Outdoor	
	Site 1	Site 2	Site 3	Primary Sample	Duplicate Sample
LAGW04	462	424	515	28	32
LAGW05	206	178	199	113	112
LAGW06	284	212	223	14	58
SCDW01	144	140	313	38	39
SCDW02	101	199	149	32	33
NVAW02	1935 [α]	1358 [α]	2108 [α]	204	248
NVAW01	69	64	160	47	38
NVAW03	58	70	119	38	26
CAEW09	63	83	103	35	97
CAEW07	47	33	53	23	23
AZHS04	174	159	191	297	24
AZHS02	69	126	94	49	33
FLGS04	441	394	440	72	45
FLGS01	-	119	146	81	53
PABS04	260	174	165	29	130
PABS03	388	371	460	44	57

[α] High dichlorodifluoromethane concentrations.

2.2.3.5 Evaluation of Cleaning Products

The procedures described in Steps 1 and 2 (Section 2.2.1: Step 1- Identification of Target Building Materials and Products; and Section 2.2.2: Step 2 - Collection of VOC-Related Product Information) above also can be used to evaluate cleaning products. The following must be considered when evaluating cleaning products: (a) residues of surfactants and detergents on fabrics and carpets may cause skin irritation and, when aerosolized, may cause eye and mucous membrane irritation; (b) cleaning solvents containing reactive hydrocarbons may result in adverse health effects; (c) cleaning powders for soiling removal could become aerosolized if not properly removed; and (d) application of polishes and waxes to hard surfaces may result in VOC emissions, especially when applied with rotary cleaning equipment. If ozone (O_3) is used during cleaning or deodorizing, then it may, depending on the resulting indoor concentrations: (a) react with other VOCs in a building, in a process similar to combustion, to form oxidized compounds such as organic acids and aldehydes which have low odor thresholds; and (b) result in odors or adverse health effects (Berry, 1994). Berry (1994) provides general guidelines on cleaning products and specific recommendations for carpet and fabric cleaning.

In California, as was mentioned in Section 2.2.3.2, the CARB regulates the maximum amounts of **reactive VOCs** (i.e., VOCs that participate in atmospheric photochemical reactions) contained in consumer products including cleaning products. These regulations can be found in the California Code of Regulations (CCR, 1993) and are listed according to the maximum percentage of VOCs allowed per product category. At a minimum, cleaning products sold or supplied for use in California buildings must meet these requirements. Table H3 of Appendix H lists these requirements for various cleaning product categories.

2.2.4 Step 4 - Selection of Low-VOC-Impact Materials

2.2.4.1 Pre-selection Process

During the pre-selection step, design professionals should consider several issues before selecting products. These considerations include the following.

1. <u>Chemical substitution or product reformulation</u>: It is important that design professionals communicate directly with product manufacturers and encourage them to develop low-emitting materials. If a product contains undesirable organic compounds, an effective communication process could result in chemical substitution or product reformulation by the manufacturer. For example, a manufacturer may be able to substitute a less hazardous ingredient in a paint or develop a low-emitting adhesive.

2. <u>Product substitution</u>: Product substitution may be a consideration in some cases. However, considerations other than VOC emission rates may need to be made when substitute products are used. These considerations may include: acoustical properties, comfort properties, local building codes, architectural characteristics (e.g., color, texture, and appearance), cost, durability, warranty, and maintainability.

   Examples of product substitution include selecting steel cabinets instead of plywood; installing pre-finished, nailed-down hardwood flooring instead of carpeting; and installing masonry flooring such as ceramic tile or marble instead of carpeting.

3. <u>Product encapsulation</u>: Product encapsulation may be another alternative. Examples include complete lamination of particleboard surfaces and coating of thermal and fireproofing insulation with a smooth impermeable membrane to reduce VOC emissions and/or adsorption and subsequent re-emissions. Care must be taken to insure that the encapsulation process does not alter the thermal, fire, acoustical or other properties of the product being encapsulated.

4. <u>Cleaning products</u>: Cleaning products need to be considered during the building material selection process. The following two examples of functionally equivalent building materials with different cleaning characteristics illustrate such considerations. Considerations other than VOC emissions rates of cleaning products must also be made. These considerations include acoustical, thermal, and aesthetical issues.

   a. <u>Comparing plastic laminates and chemical-coated fabrics for furniture</u>: Plastic laminates are easy to clean with a damp cloth using detergent and water, rinsing with clean water, and drying with a clean cloth to prevent streaking. In contrast, chemical-coated fabrics have the following disadvantages: (i) a brush must used to remove embedded soil from their surfaces; and (ii) fabrics require regular cleaning to reduce adsorption of VOCs and the resulting deterioration of the fabric.

b. Comparing hard floors and carpets: Hard floors have smooth surfaces and therefore removal of particles is easier than from carpets, which are difficult to keep free of particles. Removal of dust from hard floors can be done using soap and water. In contrast, carpets require vacuuming and shampooing which may result in release of VOCs in the indoor air. Berry (1994) states that 85 percent of the soil deposited on carpets is the result of tracked-in particulate matter and that the first two or three steps of a building entrance (i.e., 6 to 9 ft) contain most of the soil tracked inside and deposited from shoes. As a result, selection of hard flooring surfaces such as polyurethane-coated (preferably pre-finished) hardwood floors or tile floors near entrances are preferred to carpeting. In addition, appropriate mats for wiping shoes must be placed at entrances in order reduce the amount of particulate matter tracked inside a building. Placement of hard surfaces with appropriate mats at entrances could facilitate cleaning and reduce potential problems associated with cleaning of carpets in these areas.

2.2.4.2 Selection Process

Based on the results of the material evaluation process (Section 2.2.3: Step 3 - Evaluation of VOC-Emitting Products), the lowest-VOC-impact materials and products that meet each task's performance requirements should be considered. Materials that dry quickly should be preferred if functionally equivalent and similar in performance to slow-drying materials.

Figure 4 depicts a flow chart that summarizes the product selection process. Note that the chart also includes material-conditioning, installation, ventilation, and delayed occupancy considerations that are discussed in the latter sections (i.e., Sections 2.3 through 2.6).

Following is a list of product considerations for various building materials incorporating some of the factors presented in Figure 4. Note that the considerations listed below are in addition to the recommended guidelines described in Section 2 of this document.

1. Acoustical ceilings: Of particular concern are T-bar suspended ceilings used as return air plenums because both sides of the panels come in contact with indoor air. In addition penetrations for sprinklers, alarms, and smoke detectors may increase exposed emission areas considerably. Temperatures near ceiling surfaces and in return air plenums are usually higher than those in occupied zones and, as a result, increased emissions from ceiling materials may occur. Carefully consider the acoustic, fire, and aesthetic requirements for each space prior to ceiling material selection. Non-porous materials are now available that combine aesthetics and acoustical and fire code requirements (*Building Operating Management*, 1996). If porous acoustical panels are specified, follow the four-step selection process described earlier (Sections 2.2.1 through 2.2.4). Note that some acoustical panels may emit formaldehyde and that sealing of panel surfaces in order to reduce emissions and minimize VOC adsorption must be done with caution to ensure that: (a) the acoustical and fire characteristics of the panels will not be altered; and (b) application of the sealer will not result in new VOC emissions after installation.

2. Adhesives, sealants, and caulks: Specify application of only the minimum amounts of these materials necessary for satisfactory completion of each installation task. Require that adhesives have the lowest possible content of toxic or irritating VOCs while meeting other performance requirements. Require

that the manufacturers of adhesives, sealants, and caulks submit results of emission tests as well as drying times for each product. Exercise caution when interpreting adhesive emission data because such data are usually provided without the associated installed products (e.g., flooring materials) and emissions from installed assemblies may be different from manufacturers' reported adhesive emission rates.

Ensure that maximum ventilation is supplied during and after application of these products (see Section 2.5). In the case of sealants and caulks, also specify low-shrinkage products.

3. <u>Carpet</u>: Specify carpets having CRI's indoor air quality label (see Section C1 of Appendix C for a description of CRI's labeling program). Conditioning of carpets may be done: (a) prior to shipment; (b) after delivery in a dry, well-ventilated space other than the area where it will be installed; or (c) after installation. However, conditioning of carpet after installation is possible but not preferable to selecting low-VOC emitting carpeting (see Section 2.5 for a discussion of building flush outs; see Section 3.3 and Appendix D for a discussion of building bake-outs). It should be recognized that: (a) carpet emissions accelerate with increased temperature; (b) carpet emissions <u>do not</u> accelerate with increased air movement and ventilation because emissions from carpeting is a slow, diffusion-dominated process within the material; and (c) a carpet assembly consists not only of the carpet itself but also of the adhesives used for its installation (if any), padding, seaming and "floor-prep" compounds, and the underlayment or substrate. Therefore emissions from these products must also be considered.

   Refer to the CRI's Standard 104 titled *Standard for Installation of Commercial Textile Floorcovering Materials* (CRI, 1994b) for guidance on proper carpet installation. Also refer to CRI's *Carpet and Indoor Air Quality in Commercial Installations* (CRI, 1994c) for general information on their installation, maintenance, and labeling program.

4. <u>Composite wood products</u> (e.g., particleboard, plywood, medium density fiberboard (MDF), flakeboard, and hardboard): Specify low-formaldehyde-emitting products meeting HUD, HPVA, and NPA's guidelines (see Section C2 of Appendix C for a description of these guidelines), and consider completely sealing or encapsulating all exposed surfaces, including any penetrations, to minimize emissions. Complete encapsulation of all particleboard penetrations may not be possible due to addition of grommets for various applications such as power and data, that can not be accounted for in the initial building design. Note that VOC-emitting wood preservatives may be used in some of these products.

5. <u>Fireproofing</u>: Spray-on fireproofing can cause indoor air quality problems when chemical components are released into the air as a result of mechanical damage, air erosion, or deterioration of the binder. Also because spray-on materials have large surface areas, they can act as sinks for adsorption of VOCs. If possible, seal the surface of spray-on fireproofing to reduce adsorption of VOCs. Ensure that the sealer: (a) will not change fire characteristics of the original fireproofing material; and (b) is not a high-VOC emitter. Also seal any penetrations of surfaces sprayed with fireproofing material to prevent damage of the material in the vicinity of penetrations.

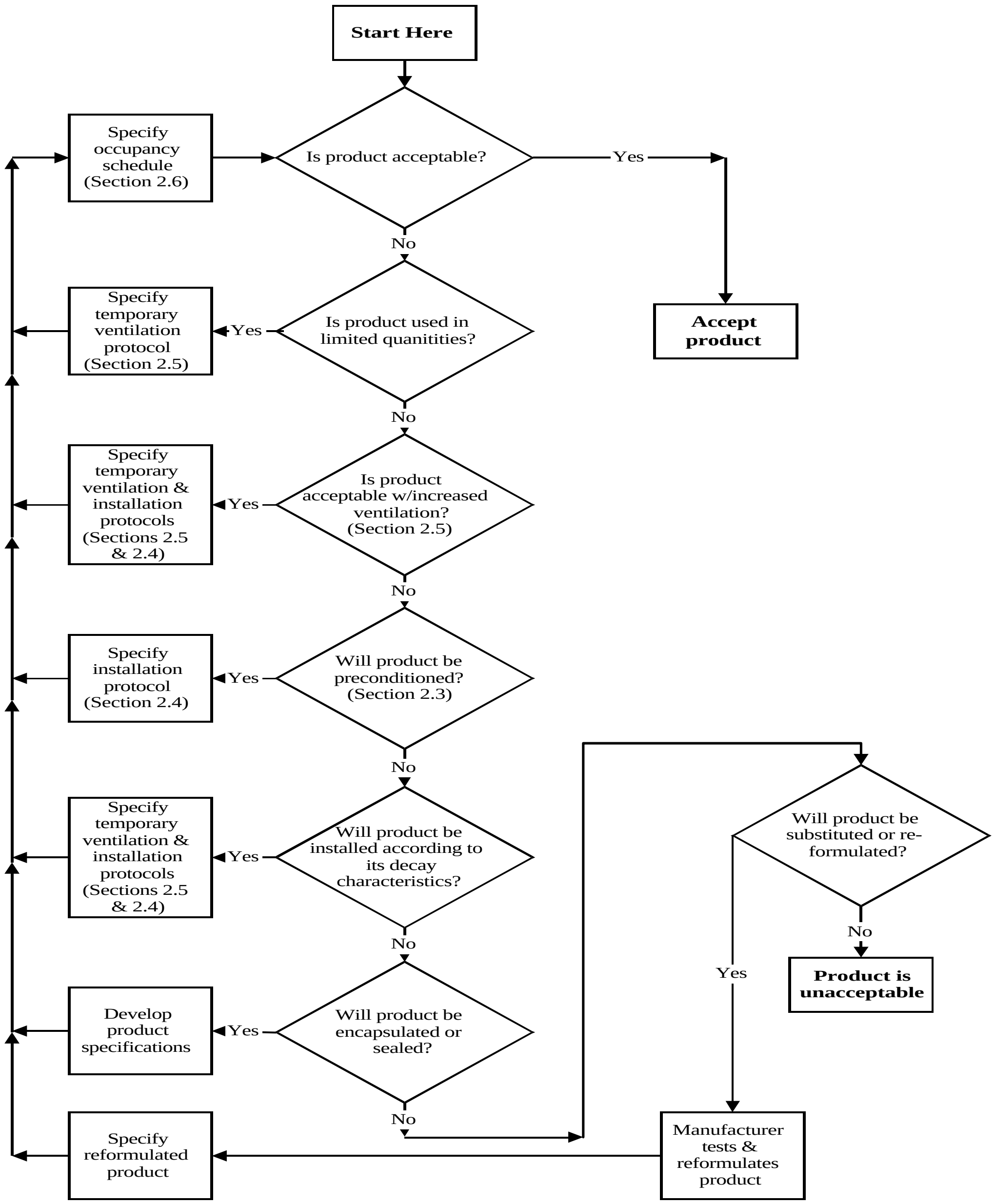

Figure 4. Flow Chart for Selecting Building Materials and Products

6. Porous materials: Pay particular attention to the sequence of installation of various products and materials, e.g., install wet-applied products first and porous materials last. When considering products that are non-porous but functionally-equivalent to porous materials ensure that acoustical and fire properties as well as aesthetics are also considered. Where acceptable, apply insulation on the exterior of HVAC ductwork and use sound baffles for noise attenuation.

7. Gypsum wallboard: Gypsum may be reasonably inert and extremely low in VOC emissions. However, additives used to produce waterproof gypsum wallboard (i.e., "green board"), fire-resistant gypsum wallboard, or to improve the workability of the slurry during manufacture may include compounds that emit VOCs. Also the paper covering on both sides of gypsum wallboard may contain chemicals from previous uses, such as in the case of recycled materials, and additives or chemicals used in the production of the paper itself. Note that VOC emissions from gypsum wallboard can be reduced considerably, but not eliminated, by painting or laminating the surfaces. The more impervious the coating or covering, the greater will be the reduction in VOC emissions from gypsum wallboard (however, VOC emissions from surface treatment materials also must be considered).

   Gypsum wallboard could act as a sink for other VOCs in the indoor air. Chang and Guo (1992) reported that unpainted gypsum wallboard has been shown to be a stronger sink for formaldehyde than painted gypsum wallboard is for other VOCs. Therefore, it is important to avoid exposing unpainted gypsum wallboard to indoor environments where strong emissions from other VOC sources exist.

   Taping and topping compounds can contain considerable quantities of VOCs. Ventilation and heat are important to accelerate the drying process of these materials. Note that formaldehyde may be present in the latex used to formulate ready-mixed joint compounds.

8. Interior panels with fabric coverings: Condition panels at the factory before packaging and shipping. Specify wrapping material that minimizes the possibility of fabric soiling and maximizes the exchange of air between the panels and the outside of the wrapping material. Also consider airing out panels prior to installation in a dry, well-ventilated space outside the building. Keep in mind that fabric coverings are porous materials capable of adsorbing chemical compounds, and therefore do not place them in environments with high concentrations of VOCs, delaying installation until emissions from high VOC sources have decreased. If cleaning or stain prevention solvents [such as 1,1,1-trichloroethane, an eye and skin irritant (see Table E9 of Appendix E)] are used prior to shipping, specify an adequate airing-out period at an appropriate enclosed, dry, well-ventilated space other than the area where the panels will be installed (see Section 2.3) prior to installation.

   Note that conditioning prior to installation may not be always practical or economical. This is due to space requirements and additional handling of panels. Space requirements may increase the delivered cost of the panels, whereas additional handling has the potential for damage.

   Also note that the surface area of interior panels varies with occupant or work station density. The surface area may approach 200 percent of the floor area in open office areas, whereas in denser installations with taller partitions this ratio can approach 350 percent. It is also important to note that both sides of interior partitions come in contact with the indoor air, and that partitions are generally located in close proximity to office workers.

9. Lath and plaster: These materials are used less in construction today than in the past. When cured, the surfaces are hard and stable, and VOC emissions are limited to those due to additives used for faster drying, better finish, or to improve other characteristics of the finished product. Use the selection process described in Section 2.2 (Evaluation and Selection of Low-VOC-impact Building

Materials) if specifying plaster with additives.

10. Manufactured casework: Particleboard is frequently used in casework because of its workability and low cost. Formaldehyde emissions from particleboard can contribute to elevated indoor concentrations. Emissions can be reduced by specifying low-emitting particleboard such as MDF and by completely sealing or encapsulating it. Small penetrations in the sealant or encapsulant should be sealed to minimize VOC emissions.

11. Paints: Minimize the use of solvent-based paints indoors. Do not use any coating indoors that is intended for exterior use. Although the use of water-based paints has been increasing over the last few years, these paints are not VOC-free and have longer drying times than solvent-based paints. Ensure that maximum ventilation is supplied during and after application of paints (see Section 2.5 for a discussion on the development of ventilation protocols).

12. Resilient flooring: Although some vinyl composition tile and other similar commercial sheet flooring may be low-emitting, these products require considerations similar to those described for carpets and carpet adhesives. It is important to specify and use the minimum quantities of low-VOC-impact adhesives that will meet the installation requirements.

13. Stone and unit masonry flooring: Stone, unit masonry, concrete, or ceramic tile flooring systems are attractive alternatives from an indoor air quality perspective. Such flooring typically utilize installation and maintenance materials and products with low VOC emissions. For example, wet-mopping typically can remove accumulated dust effectively. These materials typically are used in exteriors, utilitarian, and high-traffic areas. Note that acoustic, thermal, and aesthetic considerations must be made when using these materials in a building's interior space.

    Exercise caution when specifying sealants and finishes on these floor surfaces. The selection process described in Section 2.2 (Evaluation and Selection of Low-VOC-impact Building Materials) should be utilized for these products.

14. Tile: Sealants used on tiles or grout can be sources of VOCs. These products are formulated to dry soon after application and as a result they contain highly volatile solvents. Additional sources of VOCs include solvents, active ingredients for forming seals, additives for imparting color or changing performance and curing, and self-leveling cements. Note that excessive use of self-leveling compounds may result in expensive remediation (Light et al., 1995).

15. Treated wood: If treated wood comes in contact with indoor air, seal or encapsulate exposed surfaces. Wood treated with pentachlorophenol (PCP), an eye, nose, throat, and skin irritant (see Table E9 of Appendix E), should not be used inside buildings.

16. Wall coverings: Wall coverings can be significant sources of VOC emissions. The wall area may be as much as two to three times the room floor area in enclosed offices or conference rooms. In addition, the material area to room volume ratio (i.e., the loading factor) may be as high as 0.3 to 0.4 ft^2/ft^3.

    Fabrics, plastics, and paper wall coverings have potential for VOC emissions. In addition, adhesives and backings are also important components of wall-covering assemblies. Only the minimal amount of adhesive that meets the installation criteria should be used. Selection and installation methods similar to these for carpet adhesives (Item 2 above) can be used.

17. Waterproofing and dampproofing: Whenever application of these products is made on surfaces that come in direct contact with indoor air, choose products following the four-step selection process described previously (Sections 2.2.1 through 2.2.4).

18. Wood flooring: Hardwood flooring is an attractive option from an indoor-air-quality perspective if it is installed with mechanical fastening (i.e., is nailed down). Installation of hardwood flooring may not be appropriate or suitable for all office environments such as public buildings. Pre-finished wood-flooring products are available and their installation does not require use of any finishing products. If unfinished wood flooring is installed, adequate ventilation and curing time should be allowed during and after the application of field-applied finishes and before furniture installation or occupancy.

19. Work surfaces: Office work surfaces (e.g., desktops, countertops, and conference tables) can vary from 15 to 35 percent of the floor area. In many cases, desktop materials also are used as shelving in workstation closets adding 10 to 20 percent to the coverage ratio. Exposures to VOCs from work surfaces can be significant because both sides of these materials come in contact with the indoor air. In addition, work surfaces are in close proximity to office workers. Many work surfaces are constructed with a plastic laminate covering wood and particleboard cores. To reduce emissions, specify products which encapsulate exposed surfaces with laminates.

2.3 Development of Material-Conditioning Protocols.

One way of reducing VOC emissions from some building materials with fast-decaying VOC emission rates is by **conditioning** them prior to installation. Conditioning of building materials is a process during which materials are placed in a dry, well-ventilated area for a period of time varying from a few days to a few weeks, depending on the decay characteristics of the material being conditioned, until emission rates have been reduced to a pre-determined acceptable level. Building materials may be conditioned at the manufacturing or assembly facility, or at a bonded warehouse before shipment to the construction site in order to remove excess VOCs contained in or adsorbed on the materials. Material conditioning should be done in a clean, dry, enclosed, and well-ventilated space that is free from strong contaminant sources or residues. However, material conditioning may not be appropriate or economical in all cases. The cost of space for material conditioning may not be trivial particularly if it is done at the manufacturing or assembly site. In addition, the cost of handling a product several additional times as well as the increased potential for damage during these times also must be considered. Note that storage of certain materials after manufacturing is unavoidable especially in cases of special production orders or large quantities. For example, in the case of carpeting for a large-size building, there may be a time lag of several months between production and delivery of the product. In such cases storage is unavoidable and specifying a dry, well-ventilated space may not add a considerable cost to a project. However, rolling or packaging products after production minimizes the effects of subsequent airing out.

Materials also may be conditioned after installation. However, this is not recommended due to the possibility of VOC adsorption by porous materials. See Section 2.5 for a discussion of building flush outs and Section 3.3 and Appendix D for a discussion of building bake-outs.

Some materials may also require special handling protocols for shipping. For example, interior panels with fabric coverings treated with cleaning solvents shortly before packaging and shipment may require special wrapping materials that not only minimize the possibility of soiling but also maximize the exchange of air between the panels and the air outside the wrapping material.

2.4 Development of Material Installation Protocols (based on emissions testing)

Material installation protocols should be specified according to VOC decay rates. Materials with fast decay curves are preferable to functionally equivalent materials with slow decay rates. If materials with slow decay rates must be installed, then their impact on indoor air quality should be assessed. An extended flush-out period may be specified for several weeks after occupancy (see Section 2.5 for a discussion on the development of ventilation protocols). Schedule the installation of porous materials after VOC emissions from other materials have been reduced substantially.

2.4.1 General Considerations During Partial Building Renovation/Remodeling

Modifications in installation methods during partial remodeling/renovation can reduce VOC concentrations considerably. For example, construction could be specified to occur <u>after hours</u> while maximum ventilation is provided. As discussed in Section 2.5.1: Special Ventilation Considerations During Partial Building Renovation and/or Construction, air from construction areas should be exhausted directly to the outside and should not be allowed to recirculate or spread to occupied areas. Materials with high surface areas, such as carpets, could be <u>installed in sections</u> to reduce maximum concentrations and exposures, especially in cases where isolation of construction or remodeled areas is not possible. When installing sections of a high-surface material, enough time should be allowed between section replacement for VOC concentrations to decay.

2.5 Development of Ventilation Protocols

Two types of ventilation are commonly used to reduce indoor exposures to VOCs and other contaminants in office buildings: **dilution ventilation** and **local exhaust ventilation** (ACGIH, 1995). <u>Dilution ventilation</u> reduces VOC and other contaminant concentrations by providing "contaminant-free" air and removing an equal volume of indoor air. <u>Local exhaust</u> ventilation removes VOCs and other contaminants near their sources before they mix with indoor air.

Development of a dilution ventilation protocol during and after material and product installation is very important in reducing VOC concentrations and thus minimizing adsorption onto porous surfaces. In addition, ventilation helps accelerate drying of wet-applied materials. Therefore, a building's HVAC system <u>should be operational</u> during installation of all new materials including carpets and furnishings. Wet-applied materials, such as caulks, paints, adhesives, sealants, fillers, and coatings, should not be installed without supply of adequate air movement and maximum ventilation. A ventilation protocol also must specify that all building air <u>be exhausted</u> to the outside without passing through any return air ducts (especially any internally lined ducts). Building air can be exhausted to the outside through open windows, by removing the glass from non-operable windows, or by installing temporary exhaust fans and ducts.

Maximum ventilation should be provided continuously (i.e., 24 hr per day) for several days, weeks, or even months after material and product installation. This procedure is usually referred to as a **building flush out**. Preferably the flush out should start before substantial completion of the building and before the occupancy certificate has been issued. However, HVAC systems may not be fully operation before completion of construction. There is limited information on the length of time required for a proper flush out, but a conservative approach is to ventilate a building for as long as economically feasible, but not less than seven days. Buildings should be flushed out at occupant comfort temperatures. Flush out at elevated temperatures (e.g., 95°F or above) is not recommended due to problems associated with this procedure, such as adsorption by porous surfaces, and its questionable effectiveness (see Section 3.3 and Appendix D for a discussion of building bake-outs).

The State of Washington (1989) is one of the few public entities that recommended a flush out protocol in a major building project (see Section E1.3 of Appendix E for a brief description of Washington's East

Campus Plus program). This protocol recommended that: (a) the building flush out period to begin 90 days before occupancy; (b) all VOC-emitting material, furniture excluded, to be installed at the beginning of the flush out period; (c) furniture could not be brought in the building earlier than 30 days after the start of the flush out; and (d) the designer/builder was encouraged to continue the flush out before occupancy by the owner.

The following must be identified during the design phase of a building:

1. The need for a ventilation protocol.

2. The person(s) responsible for the operation of the HVAC system(s) during construction, before occupancy, and immediately after occupancy.

2. The party responsible for the cost of operating the HVAC system(s) during the various phases of construction.

The maximum amount of ventilation that can be provided during construction and flush out <u>may be limited</u> for a number of reasons some of which are listed below.

1. <u>Airflow capacity of an HVAC system</u>: Ventilation systems in office buildings typically can provide a maximum of 4 to 6 ACH total supply air. During typical occupied conditions, the supply air is a mixture of outdoor and recirculated air depending on outdoor temperature and humidity. However, during construction and flush out all the supply air should be <u>outdoor air</u> and no building air should be recirculated. Therefore, an HVAC system operating under increased ventilation conditions may not be able to provide the maximum amount of total supply air that could have provided under normal operating conditions as explained next.

2. <u>Heating or cooling capacity of an HVAC system:</u> The amount of ventilation may be limited depending on the outdoor air temperature and humidity and the capacity of the HVAC system. The maximum amount of outdoor air can be supplied during mild weather conditions (i.e., when outdoor air temperature and humidity are close to the design indoor parameters).

3. <u>Quality of the outdoor air</u>: In some cases, the amount of outdoor air in occupied buildings may be limited if the ambient air quality standards established by the USEPA or the California Air Resources Board (CARB) are exceeded. Weschler et al. (1992) reported that because of the potential reaction of ozone with indoor VOCs, VOC measurements at ozone concentrations above 30 ppb may be different in kind and concentration from measurements taken at ozone concentrations below 10 ppb. Weschler et al. (1992) observed that concentrations of some VOCs (e.g., 4-PC and styrene) emitted from various carpet samples in a chamber were reduced between one-third and one-tenth to their pre-ozone levels, whereas concentrations of other VOCs (e.g., formaldehyde and acetaldehyde) increased by as much as 20 times. This suggest that building flush out might be carried out during times that outdoor air pollutant concentrations typically decrease such as during nights and weekends.

4. <u>Unavoidable scheduling conflicts</u>: During certain testing tasks prior to issuance of an occupancy certificate the HVAC system may not be available for a continuous flush out. These tasks include testing, adjusting, balancing, and commissioning the HVAC system(s) as well as the building life safety systems. As a result, a building flush out may have to be interrupted for several hours at a time while these tasks occur. However, a building flush out can continue when such tests are not performed (e.g., during the night).

The proper amount of dilution ventilation, as required by the California Energy Commission (CEC) in the most recent version of the non-residential energy standard (CEC, 1995) must be supplied to a building after completion of a flush-out to ensure acceptable indoor air quality and thermal comfort. The 1995 *California Energy Efficiency Standards for Residential and Nonresidential Buildings* requires that: (a) 15 cfm per person must be supplied to a building when occupied; (b) 15 cfm per person or 3 ACH, whichever is less, must be supplied one hour before normal occupancy; and (c) before an occupancy permit is granted, supply of the minimum ventilation rates must be determined and documented.

Ensuring that the minimum amount of ventilation is supplied before and during occupancy is part of an HVAC commissioning process. Section 2.5.2 discusses a five-phase HVAC commissioning process starting before the HVAC system is designed and continuing through the useful life of a building.

2.5.1 Special Ventilation Considerations During Partial Building Renovation and/or Remodeling

Ventilation protocols are more difficult to specify in cases of partial renovation or remodeling of an occupied building. It is important to isolate physically the area under construction from the rest of the building so that air from a construction area does not enter the rest of the building. Physical isolation of a construction area includes installation of temporary physical barriers, such as polyethylene sheeting, and ensuring that return air from the construction area does not enter occupied zone(s). Air from the construction area should be exhausted directly to the outside using temporary exhaust fans. Building return air ductwork should <u>not</u> be used to exhaust air to the outside. The amount of exhausted air from the construction area should be adjusted so that the construction area is under negative pressure with respect to any adjacent occupied zones. There is very little information on the magnitude of the negative pressure that can effectively contain the air within a certain area. For example, OSHA (1994b) recommends a negative pressure of 0.02 inch of water (in. H_2O) gage (5 Pa) for negative pressure enclosure (NPE) areas undergoing asbestos abatement. In addition, Alevantis et al. (1995) reported that negative pressures above 0.03 in. H_2O gage (7 Pa) resulted in only 0.1 percent or less of air from enclosed smoking areas reaching adjoining non-smoking areas. Pressure readings between the construction area and the adjacent occupied zone(s) should be taken frequently to ensure continuous containment of the air within the construction area. Smoke tubes could be used occasionally to verify that airflow direction is from the occupied zone(s) to the construction area.

The interested reader is also referred to *IAQ Guidelines for Occupied Buildings Under Construction*, a publication available from the Sheet Metal and Air Conditioning Contractors' National Association, Inc. for more considerations for occupied buildings under construction (SMACNA, 1995).

2.5.2 HVAC Commissioning

An HVAC system performing according to design specifications is required to minimize occupant complaints related to indoor air quality including thermal comfort and airborne contaminants in new, newly renovated, and older buildings. Unfortunately in many cases, newly installed or existing HVAC systems do not meet design specifications under typical operating conditions. This is partially due to the fact that the process known as **HVAC system testing, adjusting, and balancing** is done under atypical airflow conditions, i.e., maximum-airflow conditions, and not under more typical conditions, i.e., partial-airflow conditions. Other reasons for failure to meet design specifications include incorrect testing, adjusting, and balancing of HVAC components; inability to achieve design airflows due to design and/or component installation errors; increased number of occupants, remodeling, or renovation without proper engineering evaluation of the HVAC system; and HVAC equipment failure.

A process known as **HVAC commissioning** ensures, through proper documentation and verification, that the performance of an HVAC system meets design parameters. HVAC commissioning helps reduce indoor VOC concentrations by ensuring that the proper amount of ventilation is supplied into a building. In addition, HVAC commissioning also improves thermal comfort and reduces energy consumption. HVAC commissioning should be done either: (a) by an independent party other than the HVAC designer, HVAC installer, HVAC contractor, etc., who has no vested interest in the results; or (b) by a commissioning "team." ASHRAE Guideline 1-1989, titled *Guideline for Commissioning HVAC Systems* (ASHRAE, 1989), describes five phases of HVAC commissioning that commence before initiation of the design process and continue through the life of a building. These five phases are described below.

1. <u>Pre-design phase</u>: During this phase, the HVAC commissioning parameters are set, the responsibilities of the various parties are established, and the documentation requirements are specified. All baseline information is collected, such as occupancy, building loads, budget considerations, etc.

2. <u>Design phase</u>: During this phase, the design requirements of an HVAC system are outlined. The design documents should include the following:

   a) design criteria and assumptions (ASHRAE Guideline 1-1989 lists 20 parameters including temperature, humidity, and ventilation);

   b) description of the HVAC system (such as system type, components, capacity and sizing criteria, and temperature control) and intended operation and maintenance (such as seasonal operation, occupied/unoccupied modes, and energy conservation procedures);

   c) commissioning plan, which details the implementation of the commissioning process and identifies responsibilities of key parties;

   d) documentation requirements for test procedures, checklists, report forms, calibration data, etc.;

   e) verification procedures, which include testing, adjusting and balancing, equipment performance, automatic controls, etc.; and

   f) commissioning documentation, which covers testing, adjusting and balancing, equipment performance, control schematics, operation and maintenance instructions, and as-built documents.

3. <u>Construction phase</u>: During this phase, the independent consultant or the commissioning team should observe all pressure tests of the piping and duct systems, as well as all start-up, testing, adjusting and balancing, and calibration procedures. Also, the operation and maintenance personnel should be present during this phase to observe the installation of HVAC components and receive training on HVAC operations.

4. <u>Acceptance phase</u>: After verifying that certain pre-requisites have been met (such as hydrostatic testing, flushing, cleaning, etc.), a series of functional performance tests are conducted on all equipment, using checklists developed during the design phase. Tests are conducted under all normal modes of operation, including full-load, part-load, and abnormal (i.e., emergency) conditions.

   Training of the building operator(s) continues in the acceptance phase. Operators should have a good understanding of all equipment, components, and systems and should know how to use the various operations and maintenance manuals. In addition, operators should be trained on equipment operation under all modes of operation (such as warm-up and cool-down), on acceptable tolerances for system adjustments in all modes of operations, and on abnormal and emergency procedures.

5. Post-acceptance phase: During this phase, the as-built documents are revised and any equipment changes are monitored and documented. A maintenance and service program is developed for the HVAC equipment based on the manufacturer's recommendations. A record of all maintenance and service performed also must be kept. Periodically, the HVAC system must be re-tested to measure actual performance. If actual performance is different than expected, then a re-commissioning may have to be considered. Finally, a log of all occupant complaints related to HVAC systems must be maintained. Post-occupancy commissioning or "fine tuning" is essential in ensuring that HVAC system(s) operate as designed under normal operating conditions.

HVAC commissioning is a complex process that must be followed thoroughly to ensure proper HVAC operation. The additional costs of such a process easily can be recovered from direct and indirect savings during the life of a building. Direct savings result from more efficient equipment operation and prolonged equipment serviceable life, whereas, indirect savings may include increased employee productivity and decreased absenteeism. Some utilities companies now subsidize the cost of HVAC commissioning. Building owners and managers also must realize the importance of operator training, regular equipment maintenance, and proper record-keeping. Although a mandatory HVAC commissioning program does not exist in California at this time, there are special requirements for the operation of building HVAC systems. Section 5142 of the General Industry Safety Orders, Title 8, of the California Safety Code published in 1987 titled *Mechanically-Driven Heating, Ventilating and Air-Conditioning (HVAC) Systems to Provide Minimum Building Ventilation* requires the following:

a) design ventilation rates must be supplied continuously when buildings are occupied;

b) HVAC systems must be inspected at least annually; and

c) maintenance records for HVAC system(s) must be kept and be available for inspection.

The complete language of this minimum ventilation standard is presented in Appendix J.

2.6 Development of Occupancy Schedule

Concentrations of VOCs are often highest during and immediately after construction or renovation. As a result, occupant complaints may be highest during this period. It is therefore important that occupancy of newly constructed or renovated areas be delayed until:

a) all construction has been completed including installation of floor coverings and office furniture;

b) the HVAC system has been commissioned as was discussed in Section 2.5.2; and

c) adequate time has been allowed to flush out the construction area(s) as was discussed in Section 2.5.

The adequacy of the flush out can be determined by testing the indoor air before allowing the occupants to move in. It should be noted that: (a) guidelines exist for only a few VOCs; (b) there are no standard testing methods exist for TVOCs; and (c) existing guidelines for TVOCs are not widely accepted. However, TVOC concentrations can be used to compare a building's indoor air with measurements taken in other non-problem buildings as discussed in Section 2.2.3.4.2. Due to financial constraints, building owners and managers are often pressured to move occupants into newly constructed or renovated areas as soon as they can be occupied and in some cases before construction is even completed. However, as was discussed in

Section 1.3.2, the cost of an increase in absenteeism rate of only 2.5 percent can be comparable to the cost of utilities or maintenance and operation of a building.

2.7 Air Cleaning

Air cleaning has been used traditionally for particle removal. Air cleaning equipment for particles include panel-type filters, extended-surface filters, high efficiency particulate air (HEPA) filters, electrostatic precipitators, and air washers. Removal of VOCs and other gaseous pollutants with specially designed air cleaning equipment is more difficult. Activated charcoal is one of the most widely used media in gaseous air cleaning equipment for removing VOCs by sorption. However, disadvantages of charcoal include: (a) it absorbs water vapor; (b) its sorption efficiency for water-soluble compounds can be reduced in environments of high humidity; and (c) its sorption efficiency varies among specific VOCs. Recently, air cleaning systems have been developed that utilize both charcoal and active sorbents. Presently there are no standard methods for testing gaseous air cleaning equipment.

In most cases, using air cleaning equipment to reduce VOCs and odors (such as "new carpet" odor) in buildings is not practical due to: (a) the large airflow rates that must pass through large amounts of sorbent materials; and (b) the ongoing cost of replacing the sorbent media at regular time intervals. However in some special applications (e.g., small construction areas), use of sorbent materials may be practical.

Given today's technology of air cleaning equipment and the lack of standard testing methods, use of air cleaning equipment as the primary method for reducing occupant exposure to VOCs from office building construction materials is not recommended. However, it is possible that new equipment may be developed in the future that can remove VOCs from large amounts of air in reasonable time for a low cost.

SECTION 3. OTHER MANDATED TOPICS

3.1 Appropriateness of Mandatory Regulations

The information presented in this document is the best knowledge currently available for reducing occupant exposure to VOCs from office building construction materials. However, as discussed in Section 2, available information for selecting low-VOC-impact building products and materials is limited. In addition, few standard testing methods exist for building materials and products at this time. Therefore, it is inappropriate to consider mandatory regulations for reducing occupant exposure to VOCs from building construction materials. Compliance with the guidelines is encouraged on a <u>non-binding, voluntary</u> basis. Product manufacturers are encouraged to develop <u>voluntary</u> labeling programs as more standard testing methods for various building construction materials become available.

In addition, because of the lack of sufficient field data on the optimum length of time that occupancy should be delayed in new or newly remodeled buildings, the guidelines do <u>not</u> recommend regulation of delayed occupancy. Instead the guidelines encourage building flush outs for as long as economically feasible but not less than seven days. A pre-occupancy VOC testing is also advised as was discussed in Section 2.6. Further information on the development of occupancy schedules is presented also in Section 2.6.

3.2 Need to Establish an Ad Hoc Group of Building Professionals

The usefulness of the guidelines depends on the extent to which they are disseminated to those professionals who would apply them, as well as the ease with which they can be applied and the extent to which such professionals are convinced that following them is in their best interest. Therefore, every effort should be made to: (a) ensure that the guidelines are disseminated widely; (b) ensure that the guidelines are easy to apply; (c) provide additional training in support of the guidelines; and (d) demonstrate to possible users that it is in their interest and in the interest of their employers to follow the guidelines.

According to Section 426.10 of the California Health and Safety Code, copies of the guidelines are to be submitted to the California Department of General Services (CDGS) and the Building Standards Commission. It is recommended that CDGS disseminate the guidelines to all staff with responsibility in the areas of building design and construction, leasing, renovation, and operation. The CDHS will make copies of the guidelines available to professional associations of architects, mechanical engineers, interior and business designers, building owners and managers, stationary engineers, and others responsible for building design, renovation, construction, and operation in the private sector. The CDHS also will make copies of the guidelines available to the general public.

The guidelines as they are presented here have been developed and reviewed with the assistance of professionals in the design, construction, building management, and indoor air quality fields, as well as by suppliers of building and furnishing products, and other parties interested in indoor air quality in office buildings. (A complete list of all the reviewers is shown under Acknowledgments at the beginning of this document.) In order for the CDHS to substantiate the usefulness, procedures, validity, costs, and benefits of implementing the guidelines, it is recommended that an ad hoc committee of interested parties be convened. The composition of this committee should include:

a) health experts, such as physicians and toxicologists knowledgeable about VOCs;

b) architects, HVAC design engineers, and interior designers;

c) industrial hygienists and chemists knowledgeable about indoor VOCs;

d) representatives of other State agencies with interest or regulating authority in indoor air such as the California Energy Commission (CEC), the California Occupational Safety and Health Administration (Cal-OSHA), the California Air Resources Board (CARB), and the California Department of General Services (CDGS);

e) manufacturers of building construction materials and products as well as cleaning products;

f) builders and building subcontracting professionals;

g) building owners, building managers, and building engineers;

h) representatives of organized labor; and

i) building inspectors.

The above group should further review the guidelines, and should make recommendations for modifications to them, for further testing of them in the field, and for determining if, based on reasonable dissemination, the guidelines are being used.

In addition to the formation of the ad hoc committee, the CDHS also recommends that a public agency or an appropriate professional organization serve as a central repository for, and provide a regular updated listing of, emissions testing information and current product regulations. Thus, the central repository could provide building professionals with the most current information.

3.3 Building Bake-outs

The purpose of a **bake-out** is to "artificially age" building materials and products by accelerating emissions of residual solvents. A building bake-out involves elevating the temperature of an unoccupied, newly constructed or remodeled building to between 95 and 102°F (35 and 39°C) while supplying a fixed amount of ventilation, and flushing out the building with the maximum possible ventilation after completion of the bake-out. According to Girman et al. (1987), an increase from 74°F (23°C) to between 90 to 102°F (32 and 39°C) should increase diffusion of solvents through materials by approximately 10 percent and should increase the vapor pressure of solvents by approximately 200 percent.

Various researchers have conducted a number of field trials of bake-out in actual buildings (Girman, 1989; Girman et al., 1987, 1989, 1990; Offermann et al., 1993; Hicks et al., 1990). However, the results of these studies have been mixed. In some cases, concentrations of certain compounds were significantly reduced, while in other cases, concentrations either remained unaffected or increased after a bake-out. In one case, VOC concentrations were substantially decreased immediately after a bake-out but within two weeks returned to the concentrations measured prior to the bake-out (Offermann et al., 1993).

Based on current knowledge, the building bake-out procedure is neither recommended or discouraged. The problems often associated with this process include: (a) technical difficulties such as being able to raise significantly the temperature of <u>all</u> VOC sources while providing sufficient ventilation as is discussed in Appendix D; (b) its questionable effectiveness; (c) the potential of material damage due to elevated temperatures; and (d) the potential of VOC adsorption and subsequent re-emission by porous surfaces. The bake-out procedure can be used in some situations as long as the building owners and/or building professionals are aware of the limitations and risks associated with this technique. The technical aspects of building bake-outs are discussed in Appendix D.

Instead of the bake-out procedure, the guidelines recommend the following: (a) select low-VOC-impact products and materials; (b) develop a ventilation protocol during and after construction (a method known as building flush out); and (c) delay occupancy until VOC concentrations have been decreased to an acceptable level (see Section 2).

ACRONYMS AND SELECTED GLOSSARY

ACGIH American Conference of Governmental Industrial Hygienists.

ACH air change rate per hour; the number of times that outdoor air completely replaces the volume of air in a building per hour.

A/E Architectural/Engineering.

APCD air pollution control district

AQMD air quality management district

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASTM American Society for Testing and Materials.

ATSDR Agency for Toxic Substances and Disease Registry.

BAAQMD Bay Area Air Quality Management District

building construction materials construction materials and products, major furnishings, and those cleaning and maintenance materials and products, the use of which are directly associated with the building materials selected.

building bake-out process designed to "artificially age" building materials and products by elevating the temperature of an unoccupied, newly constructed or remodeled building while supplying a fixed amount of ventilation, and flushing out the building with the maximum possible ventilation after completion of the bake-out.

building commissioning see HVAC commissioning.

building flush-out process during which a building is continuously (i.e., 24 hr per day) ventilated for several days or weeks at the maximum possible outdoor air rate.

Cal-OSHA California Occupational Safety and Health Administration.

CARB California Air Resources Board.

CAS # chemical abstracts service registry number.

CCI Canadian Carpet Institute.

CCR California Code of Regulations.

CDGS California Department of General Services.

CDHS California Department of Health Services.

CEC California Energy Commission; Commission of the European Communities.

CFM cubic foot per minute (ft^3/min); [1 CFM = 0.47 Liters/second (L/s)].

CFR Code of Federal Regulations.

CRI (United States) Carpet and Rug Institute .

dry products building materials characterized by slowly decreasing VOC emissions (e.g., floor coverings and composite wood products).

ECA European Collaborative Action.

emission rate mass of an individual volatile organic compound or mass of total measured volatile organic compounds emitted from a material per unit of time; emission rate unit is µg/hr; emission rate equals the emission factor times the sample's area.

emission factor mass of an individual volatile organic compound or mass of total measured volatile organic compounds emitted from a material per unit area of material or product per unit of time; emission factor unit is $\mu g/m^2 \cdot hr$.

FID flame ionization detector.

FLEC field and laboratory emission cell.

ft^3/min cubic foot per minute (CFM); (1 ft^3/min= 0.47 L/s).

GC gas chromatography or gas chromatograph.

headspace testing testing method that involves placing a product sample (e.g., a section from a carpet roll, a piece of plywood, etc.) in a closed container for a pre-determined period of time and then sampling the air in the "head space" above the sample in the container.

HEPA high efficiency particulate air (filter).

HUD (United States) Department of Housing and Urban Development.

HVAC heating, ventilating, and air conditioning.

HVAC commissioning process that ensures that the performance of an HVAC system meets design parameters.

IAQ indoor air quality.

IARC International Agency for Research on Cancer.

in. H_2O inch of water (a pressure unit); 1 in. H_2O (60°F) = 248.8 Pa.

loading factor (of a material or product) the ratio of the surface area of a material divided by the volume of the space where it is installed or tested.

low-VOC-impact building material or product building material or product that when installed in a building results in minimal or reduced exposure of occupants to VOCs that are emitted from the material or product.

material conditioning: a process during which materials are placed in a dry, well ventilated area for a period of time varying from a few days to a few weeks, depending on the decay characteristics of the material being conditioned, until emission rates have been reduced to a pre-determined acceptable level.

MDF medium density fiberboard.

mo month.

MRL Minimum Risk Level.

MS mass spectrometry or mass spectrometer.

MSDS Material Safety Data Sheet.

ng nanogram.

NIOSH (United States) National Institute for Occupational Safety and Health.

no-VOC-emitting product product that does not emit reactive VOCs that may participate in atmospheric photochemical reactions but that may emit other VOCs; also referred to a "zero"-VOC emitting product.

NTIS (United States) National Technical Information Service.

O_3 Ozone.

OEHHA (California Environmental Protection Agency) Office of Environmental Health Hazard Assessment.

OSHA (United States) Occupational Safety and Health Administration.

Pa Pascal (a pressure unit); 1 Pa = 1/248.8 in. H_2O.

4-PC 4-phenylcyclohexene.

PEL permissible exposure limit

ppb part per billion; 10^{-9}; unit of measure of air concentration of a gas or vapor.

porous material or product porous building material that has a large surface areas due to its rough or textured surface characteristics; porous materials act as VOC sinks (see VOC sinks), i.e., secondary sources of chemical compounds to which they were exposed and which they trapped; examples of porous materials include textiles, carpets, and insulation.

ppm part per million; 10^{-6}; unit of measure of air concentration of a gas or vapor.

RTECS registry of toxic effects of chemical substances.

SBR styrene butadiene rubber.

SBS sick building syndrome; situation in which building occupants experience symptoms, such as nose, eye, and throat irritation, sneezing, stuffy or running nose, fatigue or lethargy, headache, dizziness, nausea, irritability, and forgetfulness, and which the occupants associate with the building.

SCM suggested control measure.

sink effect see VOC sink.

TCE Trichloroethylene.

TLV threshold limit value.

TVOCs total volatile organic compounds; sum of air concentrations of individual VOCs

USEPA United States Environmental Protection Agency.
.
VAV variable air volume; a type of HVAC system that varies the volume of supply air depending on thermal requirements.

ventilation (dilution) process of supplying "contaminant-free" air to a space and of removing an equal volume of indoor air from this space by natural or mechanical means; the supplied air may or may not be conditioned.

ventilation (local exhaust) process of removing VOCs and other contaminants near their sources by direct exhaust to the outside.

VOC volatile organic compound typically sampled by adsorption on a solid sorbent that has a sufficiently high vapor pressure to exist as a gas or vapor at ambient temperatures, i.e., with lower boiling point limit between 50 and 100 °C and an upper limit between 240 and 260°C (this definition is based on the methods used to sample VOCs); however formaldehyde and some other compounds are included for convenience although they do not have boiling points between 50 and 260°C.

VOC (reactive) volatile organic compound; the USEPA (1983), the ASTM (1993), and the CARB (1993a) list the following operative (i.e., not physical) definition: *any organic compound that participates in atmospheric photochemical reactions, i.e., any compound containing at least one atom of carbon, except methane, carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, ammonium carbonate, 1,1,1-trichloroethane, methylene chloride, trichlorofluoromethane (CFC-11), dichlorodifluoromethane (CFC-12), chlorodifluoromethane (HCFC-22), trifluoromethane (HFC-23), 1,1,1-trichloro-2,2,2-trifluoroethane (CFC-113), 1-chloro-1,1-difluoro-2-chloro-2,2-difluoroethane (CFC-114), chloropentafluoroethane (CFC-115), 2,2-dichloro-1,1,1-trifluoroethane (HCFC-123), 1,1,1,2-tetrafluoroethane (HFC-134a), 1,1-dichloro-1-fluoroethane (HCFC-141b), 1-chloro-1,1-difluoroethane (HCFC-142b), 2-chloro-1,1,1,2-tetrafluoroethane (HCFC-124), pentafluoroethane (HFC-125), 1,1,2,2-tetrafluoroethane (HFC-134), 1,1,1-trifluoroethane (HFC-143a), 1,1-difluoroethane (HFC-152a), and the following classes of perflurocarbons: (A) cyclic, branched, or linear, completely* *fluorinated alkanes; (B) cyclic, branched, or linear, completely fluorinated ethers with no unsaturations; (C) cyclic, branched, or linear, completely fluorinated tertiary amines with no unsaturations; and (D) sulfur-containing perfluorocarbons with no unsaturations and with the sulfur bonds only to carbon and fluorine.*

VOC sink material that adsorbs VOCs; a VOC sink typically adsorbs VOCs when air concentrations are high and re-emits them when air concentrations decrease.

wet product building material with high solvent content characterized by relatively high VOC emissions during and immediately after installation followed by much lower emissions (e.g., paints and adhesives).

WHO World Health Organization.

zero-VOC emitting product see **no-VOC-emitting product**

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